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Towards reconnecting Computer Science Education with the World out there

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Dedicated to Prof. Matteo Bonifacio.

Abstract

Computing is becoming exponentially more pervasive, and the so-called process of "Digital Transformation" is but starting. As computers become ever more relevant, our societies will need computing professionals that are well-equipped to face the many challenges their own discipline amplified.

The education of computer scientists, so far, mostly focused on equipping them with technical skills. Society and academia, however, are increasingly recognising computing as a field where disciplines collide and intersect. An example that we investigate is that of Innovation and Entrepreneurship (I&E), a field that has often be used to equip computer science students with soft skills and non-technical competences.

Computer science faces some unique problems, among which a lower student interest for non-technical subjects, and a constant process of epistemic and technological obsolescence. This thesis showcases some experiences that aim to address these challenges, going towards (re)connecting the Humans and Machines participating in computer science education with the needs of the World of today and tomorrow.

Our work combines some theoretical reflections with pedagogical experiments, to ensure that our work has at the same time descriptive power and empirical validation. To aid teachers and learners in the change process, these experiments share a pedagogical approach rooted on Active Learning, ranging from Challenge-Based Learning to Peer Education, to custom-tailored teaching methodologies. In designing each experiment, we start by asking ourselves: how is what we want to teach practiced in the real world?

Theoretically, this thesis contributes to the state of the art by conducting a horizontal exploration of how computer science education can enter an *age ever more dominated by so-called ambiguity.*

Methodologically, we propose lightweight techniques for qualitative measurement that are rigorous, but introduce little methodological burden, emphasising our work's reflective and exploratory dimension.

Our work aims to show how, using the same broad design process, courses can be flexibly adapted to fit an ever-changing world, including significant disruptions such as the transition to online education.

Keywords

computer science education; innovation and entrepreneurship; active learning; education technologies; higher education consortia

Acknowledgements

Researchers use acknowledgements to give credit to people that contributed to a body of work, but not to a level that considers them co-authors.

I wish to challenge this notion. What is a greater act of co-authorship than being there to support one's growth and livelihood during one's phase of life, or while they work on a major endeavour?

Unfortunately, I need also to play by the rules of the game. So while I need to claim this as "my" work, I prefer to think of it as "ours". If research is about standing on the shoulders of giants, this section represents the literal shoulders, or hands, or emotions, or minds, upon which, very often, I have relied on in the strictest sense. They may not be literal giants, but they have been just as reliable.

It'll be a long one. Bear with me. Incidentally, after writing this, I realised I predicted this on my Master's thesis. In doubt, I guess I can always blame the template for the length. So, with some order (but please don't read too much into it), I would like to thank...

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This is for all of you who are still here, and dedicated to those who are not anymore.

[1]As of the time of writing.

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Chapter 1

General Introduction

1.1 Context

Where is education in our public discourse? With all the talk about business, innovation and research, a surprisingly small amount of attention seems to be directed towards what generates them, their hidden driving force. Even in 2020, as schools finally re-entered the mainstream public debate (though, ironically, because they were closed), very limited attention was given to what was happening in universities.

University education occupies a peculiar niche: we see their participants (the students) neither quite as children in need of tutelage, nor as independent professionals. With substantial exceptions, the mainstream perception of university education is that it maybe is not even "education", but more like instruction. Pedagogy, in university research, has a limited place — the focus should be on content. Even in education research, work on school education, the so-called K12[1] age range, vastly outnumbers work in higher education, be it at undergraduate or graduate level.

The realm of so-called STE(A)M[2] higher education faces an extra challenge in its perception. As the source of much of today's innovation,

[1]Kindergarten to 12th Grade.

[2]Science, Technology, Engineering, (Arts), and Mathematics.

STEAM professionals are expected to be competent in their fields, but also able to innovate, solve contemporary challenges, and communicate the results of their work to the public.

But what do we risk missing about this vision, when we limit the space of pedagogy in STEAM university education? A striking possible answer was given by Belski [24]: as they go through university, would-be engineers' problem solving skills *decrease*! What makes this even more paradoxical, however, is that education research and policy has been advocating for the need to rethink higher education pedagogy for a long time.

In this work, we will discuss this situation from the perspective of Computer Science (CS). CS occupies a particularly interesting position: as one of the youngest macro-disciplinary areas in human knowledge, one would expect CS to be quicker to adapt, and to be less encumbered by its own legacy. Instead, we will see that CS has also developed a significant gap between how it is taught in higher education and how it is practiced outside academia.

In spite of (or thanks to!) its young age, we can reconstruct how this gap developed, and trace its evolution from philosophical thought to industrial practices. Most importantly, however, we can also propose some pedagogical actions to start bridging this gap, and truly take some steps ”Towards reconnecting CS education to the World out there“.

Our journey has been extremely broad, with forays, among others, in epistemology, pedagogy, entrepreneurship, sociology, and of course computer science proper. This breadth has sometimes been a hindrance, as it has — especially in the beginning — made it harder to position our work in the literature, but it has mostly been an invaluable asset in creating a more comprehensive perspective on what might be needed to tackle this challenge.

1.1.1 How did we get here?

CS curricula generally dedicated an extremely limited amount of time to discussing the history of the discipline. Most computer scientists know of Alan Turing, but an arguably equally important figure in defining the origins of computer science has been that of Nobel and Turing prize laureate Herbert Simon. Grasping Simon's theory of bounded (or procedural) rationality [196] is a key step to understand the mental models underlying early forays in CS.

Without going too much in depth in this topic, it should suffice to say that, in retrospect, many of CS's early theories can be seen as having a positivistic connotation: bounded rationality works under the underlying assumption that, with an infinite amount of resources to conduct search routines, a globally optimal solution will be found [197].

In the following decades, however, and partly as a consequence of the success of CS itself, the philosophical and epistemological worlds started to see the rise of post-modernism and subjectivism. Today's highly connected era makes it hard to argue against the role of CS in often making reality *harder* to understand and more subjective, in what some called a "post-true", or "unreal", world [242].

Outside CS, however, many disciplines extensively discuss the evolution of their philosophical thought in higher education: from economics to sociology, history is included in many educational curricula. The lack of discourse around the history and epistemology of CS reflects in its teaching: CS is seen as as an exclusively technical subject, while a growing number of voices — even included into the Communications of the ACM[3] — is starting to argue for CS to be considered a social science [62].

Even in the discussion surrounding computing ethics, there is no con-

[3]The Association for Computing Machinery, the largest academic society for Computer Science research and education.

sensus on whether CS is generating *novel* ethical challenges, or it is just *enhancing* existing ones. An economist's perspective might argue that, when a certain point is reached, a difference in scale becomes a difference in scope [47]. There is agreement, however, on one fundamental point: the fast development of CS is not without consequences. We further argue though that these consequences are not explored enough in CS education: they are *underrepresented challenges in CS education*.

1.1.2 What are we missing?

A fast-moving field does not simply generate new knowledge: it also obsolesces a significant portion of the knowledge it iself has produced [35]. Ironically, CS demonstrates this property in a strikingly tangible way: computing devices obsolesce — and are thus discarded — at blazing, and increasing, speed [12].

The case of so-called e-waste highlights the interconnection between CS and one of the most critical crises humanity is facing: the climate crisis. Yet, in spite of its pivotal importance, CS education rarely covers the intersections between CS and other disciplines. As an equally striking example, we can also look at the impact of CS in generating economic wealth — and exacerbating inequalities: of the 100 richest people in the world, 23 are technology executives, holding a total wealth of over one trillion dollars [68].

There are countless more paradoxes, or otherwise underrepresented problems in CS education, of this kind.

The internet, as an enabler of knowledge diffusion, also requires radically different competences for its use[4]. The information age made it so that the focus of learning is not in knowledge acquisition, but in knowledge assessment, yet students are woefully unprepared in this aspect [82].

[4]The so-called "digital literacy".

Open Source software is now powering a vast majority of our world's economy and knowledge engine, with even practices adopted in Open Source development making their way into the industry [200]. In spite of this, however, the increasing complexity of our technological stacks makes it harder and harder for individuals to understand the technologies they use and that enable the information sharing to begin with.

The social impacts of CS are also not widely understood: the ethical and social consequences of implementation choices are rarely discussed, with computing ethics entering the general discourse only recently due to the speed of advances — and problems — of Artificial Intelligence.

We take the stance that all of these underrepresented problems — and more — reflect how CS was not able to adapt to the world it itself has so radically reshaped. Literature has variably called the contemporary world's landscape one of "ambiguity" [213], to mark the difference with Simonian or Knightian "uncertainty" [119]. Our work wants to show that, to make CS education more prepared to deal with the global transformation of today and tomorrow, the first step is to recognise and welcome ambiguity in education.

1.1.3 Goal

We can summarise the goal of this thesis as follows:

> This thesis **showcases concrete actions that address underrepresented challenges in CS education *starting from the humans*, i.e., through pedagogy, rather than from the tools**. Combining a number of disciplines, we highlight how **computing is not enough to comprehend the far-reaching impacts of computing itself, requiring instead an interdisciplinary view and flexible assessment frameworks** that

are able to quickly be adapted when — inevitably — further change will be needed.

To achieve this ambitious goal, we cannot rely on literature sources and methods of one single discipline: in many ways, this work represents an attempt at approaching research with a "generalist" eye, acknowledging that the intersection and cross-pollination between disciplines represents fertile grounds to discover novel insights.

We also acknowledge that the scientific and academic process is the main way to produce reliable knowledge but that, especially in fields that are hard to frame within the boundaries of individual journals or conferences, highly-relevant knowledge is also encountered in books, policy documents, practitioner articles, informal literature, practices, or even oral tradition.

As we will discuss in the next section, our theoretical and methodological tool box needs to be as well-equipped as possible to achieve results that are not only significant and measurable, but also visionary and relevant.

1.2 Theories and methods

A tool box is only as useful as it is well-equipped and well-organised. If we are to tackle our ambitious goal, we need to ensure that we have tools that are able to address the whole educational stack — from grounding theory to pedagogy — and that the relationships between them are clearly defined. The dangers of not taking such full-stack approach are excellently synthesised by Thomas [220] who, using Furlong and Lawn's words, warns that education studies are trading off descriptive power in favour of "routinized method[s] and atheoretical empiricism".

As a consequence, our tool box is designed to work in two directions: towards theory, with epistemology; towards practice, with pedagogy.

On the epistemology side, we discuss the phenomenon of complexification of the knowledge landscape in the form of "ambiguity". We present two theoretical tools that allow us to navigate ambiguity: James March's Garbage Can and Bruno Latour's Actor-Network Theory (Actor–Network Theory (ANT)). The Garbage Can and ANT give at the same time a theoretical backing to our inquiry and provide education researchers, teachers, and students alike some possible ways to navigate this ambiguous knowledge landscape.

Methodologically, a set of models inspired by the well-established theory of constructivism and the newer pedagogical model of Challenge–Based Learning (CBL) give us some possible way to translate our theoretical reflections into practice.

It might seem excessive to start our reflections from epistemology, normally considered a branch of philosophy. At a first glance, it would be akin to starting a thesis on automobiles by discussing wheel building. Putting epistemology as the first step, however, we have the chance to go to the crux of the matter by comparing the two ends of the computing pipeline:

philosophical thought, and the social dynamics processes that emerge from the use of computing artifacts.

Since our goal is to produce an educational action, however, we need to quickly traverse the many domains of knowledge tangential to our work to convert these theories into teaching methods that can be deployed and assessed. In this sense, what we present in this section is our *theoretical tool box*, a set of lenses to analyse our space of intervention at varying levels of detail. Swapping between our available lenses, we see the emergence of different patterns — and thus different opportunities for action.

A vast majority of these lenses are drawn from two disciplines: epistemology and pedagogy. The combination of these gives us many approaches to approach the design of educational interventions, allowing us to flexibly create connections between theories and practices.

We will start from the description of a key concept that underlies all of our reflection — ambiguity — as the environment where even uncertainty is not enough to obtain knowledge. We will then take two theoretical tools that have been collocated in the space of ambiguity, and describe how they inform our mental models for the teaching of the disciplines we discuss in this thesis. We then connect these two theories with suitable pedagogical methods, and finally discuss what emerges from this combination of theories and practices.

1.2.1 Ambiguity

We use the label "ambiguity" as a term to gather any knowledge environment that Simonian/Knightian uncertainty is not able to describe. By taking Knight's definition of uncertainty [119]:

> *We shall accordingly restrict the term "uncertainty" to cases [of non-measurable risk]. It is this "true" uncertainty, and not risk,*

> *as has been argued, which forms the basis of a valid theory of profit and accounts for the divergence between actual and theoretical competition.*

We can derive ambiguity by expanding this definition in two ways: 1) by stating that risk is not only impossible to calculate because of bounded limits, but would be impossible to calculate even without limits; 2) by stating that there is no such thing as a risk to measure, taking a subjectivist stance.

An overload of definitions of ambiguity exist in the literature, some of which actually describe what we have called uncertainty. Despite the equivocal potential of this word[5], explorations in the epistemology of ambiguity historically emerged soon after the definition of uncertainty [54].

Since the early days in this space, the literature refers to a feature of "ambiguity tolerance" that people possess [203]. This concept has also been explored in the higher education context [217], and is one of the building blocks for Matzler's theory of intuitive decision-making [142]. With a more recent perspective, we can draw a link between ambiguity and Kahneman's analysis of human cognitive biases [113] — without needing to take a stance on whether ambiguity generates biases or biases generate ambiguity. Cognitive psychology gives us a possible origin for ambiguity: the limits (the bounded-ness?) of our senses and cognition.

Cognitive limits are prominently encountered in cases of information overload. Under this lens, we can also look at phenomena such as "fake news" as cases of information overload, leading to one's inability to make sense of their context, and thus to ambiguity. Social processes, with their complexity, are also often at the source of ambiguity [148].

The question that we (and others before us) pose at this point is: what space does ambiguity occupy in our field, that of computer science educa-

[5] Saying that the word "ambiguity" is ambiguous would have been in poor taste.

tion? To answer this question, we take two theories that have been in the past been classified within the label of ambiguity: James March's Garbage Can decision-making model and Bruno Latour's Actor-Network Theory.

Theories and arguments surrounding ambiguity are rooted in subjectivity, acknowledging that all attempts at analysing ambiguity are taken from a specific point of view, and are, ultimately, susceptible to being falsified by changes in context or involved actors. Our work, from a theoretical this sense, also falls in this category: we discuss how exploring *one's* garbage cans and actor-networks one can tailor effective learning methods *for their context*.

In particular, March's Garbage Can is a precious model to highlight how contemporary knowledge-making processes rarely proceed linearly, and instead involve elements of chaos, subjectivity and chance. Latour's Actor-Network Theory, instead, is a useful mapping tool to uncover how designed artifacts influence our interactions, uncovering substantial hidden complexities[6].

March's Garbage Can

James March's Garbage Can model, first described in his 1972 paper [54], has been variably applied to describe many processes of organisational learning and decision-making [137].

At its essence, the Garbage Can describes the outcome of decisions as the serendipitous aggregation of four streams: that of problems, solutions, participants, and choice opportunities. Through their apparently dis-organised interaction, these streams produce results that are highly contextual and hard to dissect.

March argues, furthermore, for a reversal of the role of time as something that is controlled by humans. His conceptualisation of temporal orders

[6]Or, in Latour's words, to "open black boxes" [124].

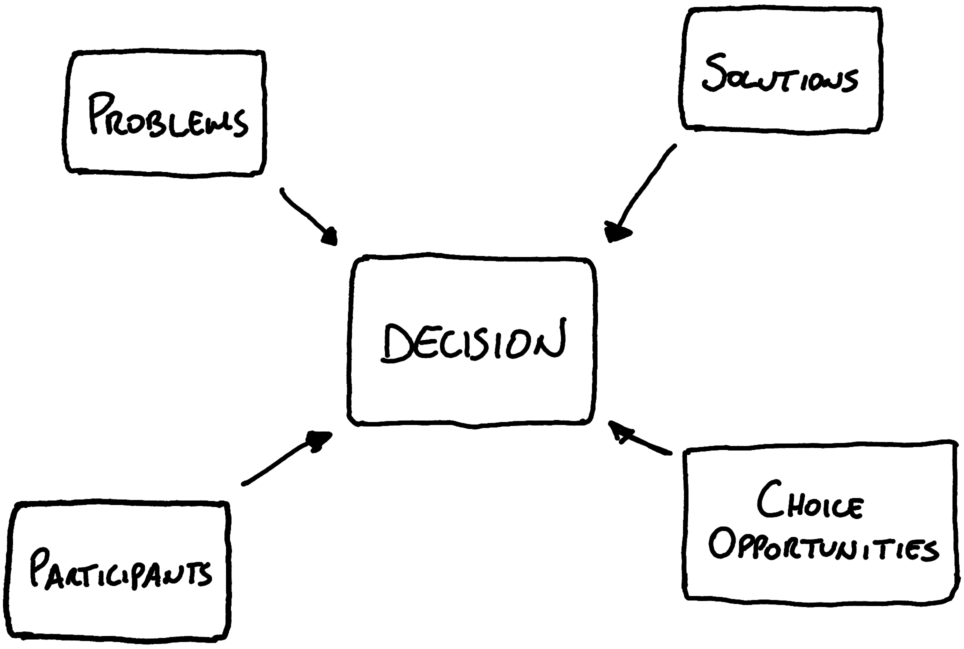

Figure 1.1: James March's Garbage Can decision-making model, visualised.

[137] suggests that one does not manage time; instead, time is the manager. If time is the manager, and decisions are taken from garbage cans, we see how we can ascribe the connotation of "ambiguous" to March's world view.

The garbage can model gives a different perspective under which we can see learning in the classroom: teachers might design educational experiences to the best of their abilities but, if the underlying world and social processes are ambiguous, their classrooms will include a substantial dose of ambiguity.

It follows, then, that we should ask ourselves the question not of how to resist this ambiguity, but how to build tolerance for it, leverage, and even welcome or seek it — what Nicholas Taleb called "anti-fragility" [215].

While it substantially disrupts our reassurances about the linearity of knowledge-making, the Garbage Can is also an invaluable tool to highlight that all of its streams have a role in decision-making, and thus in knowledge building. It is not a matter of just looking at problems and solutions, but we should devote equal effort to understanding choice opportunities and, especially, participants.

With a hint of irony, we also use March's garbage can to describe our own work. Obviously, scientific research follows the scientific method: hypotheses lead to experiments, whose results lead to a refinement of hypotheses. Successful scientific processes, in a Popperian sense, are those that *falsify* our previous knowledge, and opportunities to question our understanding of the world are never-ending.

Describing our inquiries following the garbage can model gives us the freedom to recognise the double-loop learning that happens between learning and practice [13] through the continuous interaction of the garbage can's streams. Problems and solutions streams represent our theories, choice opportunities our experiments.

But what of participants? Who or what are they? To find an answer to these questions, we will make use of our second theoretical lens, that of Actor-Network Theory.

Latour's Actor-Network Theory

Bruno Latour's ANT has a less linear history. It originated from the joint work of Latour and Callon on the "sociology of translation" [42] and phenomena of "enrolment" [43]. ANT, in Latour's own words, is "not a theory" in its scientific meaning [127], but rather a tool to map the relationships between various "actors" in a socio-technical system.

Actors, in the context of ANT, can be both humans and non-humans, either as natural elements, physical artifacts or even intangible artifacts such as laws, customs and practices [126]. Actors are described in their relationships through the principle of generalised symmetry [42]: the analyser of a system can put humans and non-humans at the same level, transparently describing their interactions simply as "actors", without discriminating humans from non-humans.

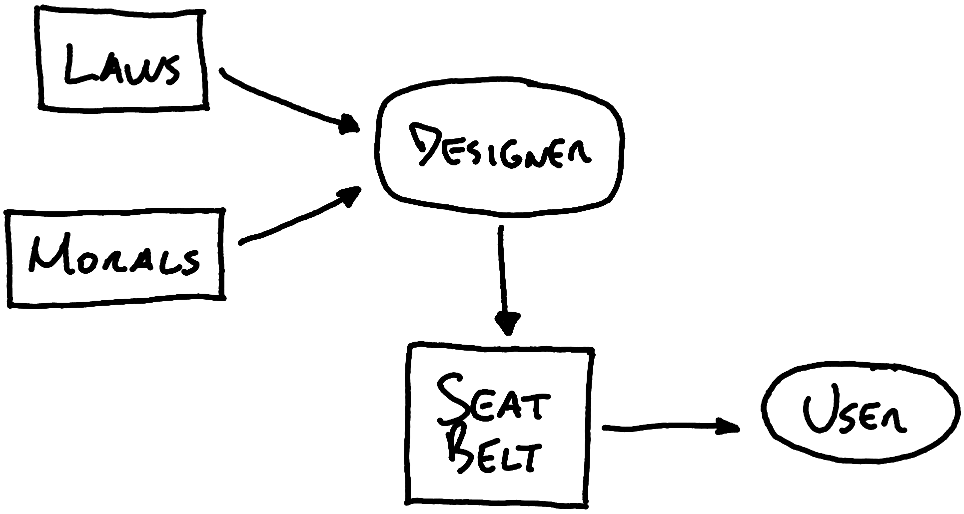

Figure 1.2: An simplified "ANT map" describing the interactions in the famous seat belt example described by Latour.

ANT has been sometimes called animist by virtue of its attributing agency to non-human actors. In our context, however, we adopt the view (also held by Latour) that non-humans have a different form of agency, one that is in-scribed [5] into objects through the intents of their designers [126].

Designer's intent can be found embedded in all non-human actors, whether physical or not. This has two strong implications on our work: on the one hand, it makes ANT a powerful lens to ask ourselves the question of what are the embedded designers' intents in our classrooms; on the other hand, it empowers us in our own designs, as we know that the practices and methods we create will help us embed our intents in the educational context.

The interaction between education and ANT has been explored in a book by Fenwick and Edwards [79][80], who also stress how ANT is a tool to open black boxes, unravel complexities, and inspire action. As we are addressing CS education, the opportunities to make use of ANT are abundant: not only there are pedagogical and social practices to analyse, CS education is naturally full of technological artifacts and machinery!

In "Aramis" [125], Latour gives a stylistically peculiar example of how ANT can be used to analyse technologies: Letour discusses the case of the never-completed Aramis transport system by interviewing stakeholders, combining historical fragments, sometimes even making the Aramis train itself speak. Aramis is an example of how what seems to be a technological problem is in fact one that involves politics, individuals, organisations... and a fair bit of garbage can decision-making.

We see ANT is a tool for sense-making and empowerment, combining the expressive power of what practitioners call information architecture [64] with social sciences, making new opportunity spaces appear, and suggesting potential courses of actions.

Ultimately, both ANT and the garbage can represent examples of the process of social construction of knowledge, with the important note of acknowledging what we have called "ambiguity". This understanding of ambiguity as a space that can be navigated through social construction of knowledge is what informs our choice of pedagogical methods.

1.2.2 Educational Methods

The development of theories of social construction of knowledge happened in parallel in the fields of sociology and of education. In the latter field, the 1900s have been dominated by the rise of "constructivist" theories of education, represented by thinkers such as Maria Montessori, Lev Vygotsky and most prominently Jean Piaget [8].

At its essence, constructivism refers to the idea that knowledge is not imparted from teachers to learners as a uni-directional flow, but rather it is *constructed* through social interactions, in an interplay between all people in the learning space.

From this general principle, the last decades have seen the creation of a vast number of education methodologies inspired by constructivism, together with a number of derivative theories of learning. Without delving on a comprehensive analysis of theories of learning and educational methods, that might well make for a thesis of its own, we want to briefly outline here the methods that we have adopted in our work, why they were chosen, and what is their interaction with the theories we have discussed in the previous section.

As a premise, we should stress that already in the 1980s, X called constructivist education methods "dominant" in the current higher education landscape. While for sure their popularity has been on a steady increase, lecturing still remains the prevalent teaching method [40]. The contributions of this thesis should not be seen merely as bringing constructivism into CS education: what we emphasise here is the strong entanglement between pedagogical methods, subject-matters, and the global context in which they are situated in.

As far as *theories* of learning are concerned, constructivism gave birth to two other influential educational theories: Papert's constructionism [1] and Siemens' connectivism [194].

Papert's constructionism entangles constructivism with the making of *physical artifacts* and the idea of learning through tinkering. Currently, CS widely employs constructionist teaching methods, from block-based programming, of which Scratch is probably the most known example[7], to maker education, which we discuss extensively in 3.3.

Siemens' connectivism, as a relatively newer theory of learning, has not yet given birth to a consolidated literary corpus. Nonetheless, it can be seen as the grounding of many policy and informal documents that discuss the

[7] Scratch is quite directly derived from Papert's work, as his designer is his former student Mitchel Resnick.

process of digitalisation of learning, such as the World Economic Forum's 21st century learning skills agenda [82] or the ACM's Computing Curricula [2].

We will discuss in their respective sections the educational methods that we employed in our instantiations. At this level, however, we want to highlight one particular teaching method that we do not explicitly explore elsewhere: Challenge–Based Learning (CBL).

CBL, first outlined by Apple's Nichols and Cator in 2008 [151], holds a particular position in our pedagogical tool box because of its sourcing of challenges from "the World out there". In many ways, it represents a flexible extension of Problem-Based Learning that expands the class' actor-network through the direct inclusion of non-academic actors in the learning process.

This extension of the class' structure grounds learning into practice bringing, as a trojan horse, the world's ambiguity into the classroom. We see CBL as the first example of a category of learning methods where (higher) education makes an explicit effort of rooting its learning practices into the wider world's practices, renouncing its privileged position in the so-called "ivory tower".

1.2.3 Guiding principle

From this understanding of epistemological theories and educational methods, we derive the general guiding principle — and core argument — that underlies this whole thesis work:

> We design our pedagogies for CS education explicitly entangling content with context, giving rise to methods that follow how technologies and subject-matters are encountered in the field.

In other words, we see pedagogy as a tool through which we can *enrol* the other human and non-human actors that participate in the educational space to align them with our intents. As designers of education, pedagogy can and should be used to embed our intents (in the form of Learning Objectives) in the educational processes.

This idea is underlied by a special attention towards the local and the hyper-local, inspired by critique work such as Jandrić's and Selwyn's [188]. Going back to our Goal (1.1.3), we wish to reject what Selwyn calls the "one size fits all" ambition of education research — and of educational technologies (EdTech) in particular — to propose practices that critically address what is needed in the context they operate in.

1.2.4 Methodological note

During our work, we often encountered two objections: first, that our broader work does not build upon a single literature stream; second, that produced results are not significant. We want to briefly address these concerns, and highlight how this is a deliberate choice.

This thesis lies at a major disciplinary crossroads, something that is not frequently found in the domain of sciences and engineering. While this work is situated in Computer Science, it would lose much of its meaning and potential for generalisation if its connections to sociology or education were to be severed in the attempt to form a single-stream inquiry[8].

As our world becomes increasingly complex, we think that there is a high risk of acquiring a form of tunnel vision that privileges the finding of data patterns over contextual awareness. Though humanity produces and shares knowledge at unprecedented speed, we want to explore what opportunities emerge from deviating from the norm of incremental specialisation. Indeed, work such as Kuhn's [121] suggests to us that over-specialisation might be a symptom of a scientific crisis, anticipating a change in paradigm.

[8]Or, in Bersteinian terms, a "singular".

This choice has the effect of what can be seen as a drawback in research: a focus on high-level design and implementation have so far meant, in the economy of our work, a lesser effort devoted to sophisticated statistical analysis and production of "objective" data.

While we do all that we can to document our processes and results, ultimately, in the often-quoted trade-off between significance and relevance, our work tends to favour relevance, aiming to trigger actionable reflections on our "underrepresented challenges".

Of course, we see significance and reproducibility as highly desirable qualities, but we argue that achieving them might require a different approach compared to what has been so far explored[9].

The work that we have carried out represents, in many ways, a work of "action research" — indeed, the author and his interventions are intimately entwined with the context where they have been carried out. From the University where our experiments have been carried out, to the consortia that have (among other things) funded the experiences, our work needs to be aware of the network of relationships in which it is embedded.

A design principle of all work carried out in this thesis is that, when discussing the reproducibility of our work, the authors do not aim to empower readers to reproduce results, but rather *processes*. Research such as what we present in this thesis is extraordinarily prone to observer biases, as is a substantial amount of qualitative or action research in education. Through extensive analysis of our pedagogical intervention — and of the meta-process of their design — we hope that readers will be able to look at our endeavours with a critical eye, triggering questions of how our work can and should be adapted to their own contexts.

[9] We discuss this further in our Conclusions section.

1.3 Structure

The present work is structured around three main Chapters, each being one category of actors that we deem needs to be enrolled in order to go towards bridging the disconnect between CS education and the world out there. Each of these categories and chapters also represents a grouping of actions that we have carried out during the last three and a half years of research. Namely, these are:

The Human — Representing non-technical education in CS, or how CS explores the "human" matters it so often disrupts. In this work, we will cover so-called Innovation and Entrepreneurship (I&E) education as a representative of "human" education in CS.

The Machine — Representing technical education in CS, or how CS sees technical matters. In this thesis, we will take the case of programming courses and maker education as representatives of this class.

The World out there — Representing how CS (and CS education in particular) generates impact in the world. In this thesis, we will discuss the case of European Higher Education consortia to showcase how education policy can bring our reflection into practice.

In the chapters on "the Human" and "the Machine", we will further make a distinction between what is the "Main Story", interventions in activities that are formally part of students' curricula; and what is the "Side Story", interventions that are extracurricular or less formal.

We will analyse the situations that surrounds the Main Stories using the garbage can model that we have presented in 1.1: we will give a general description of the streams of problems, solutions, and participants on that space, and discuss how these streams interact and intersect. Choice opportunities, the fourth garbage can stream, will be composed by "instantiations", our published articles.

Framing our own work as a garbage can is a way for us to practice our stance towards ambiguity (see 1.2.1): after all, if we wish to equip our students to welcome ambiguity, how could we shy away from it? Structuring our work too tightly would have represented a lost opportunity, and an internal epistemological contradiction.

The chapter on "the World out there" serves a different role: it represents a subjective map of our experimental contexts, and a way for us to present how work in this field can generate an impact. If we see our World as one made of communities, that chapter qualifies some of the communities we have encountered, and hopefully gives some heuristics on how to match one's work to suitable communities.

1.3.1 A note on readability

One of the goals of this thesis, as in theory is for all academic work, is to leave something that is re-usable, that can be cited and built upon.

Sadly, the scientific community seems to have gathered unprecedented consensus around a practice that is quite counter-productive: opacity in writing. An informal work published in Nature shows exactly that "science is getting harder to read" [198] at accelerating speed: meaning is hidden through the (over)use of jargon, acronyms are used excessively, complex statistics is used to obfuscate the flimsiness of research results.

In a field such as education research, reproducible results are extremely hard to obtain: data is inherently subjective, dependent on context, prone to observer biases. Obviously, education is also such a field where it is impossible to set up a double-blind experiment.

We could have taken the decision to follow this trend: write in a complicated manner, hide our naïveté, take our position among *scientists*

— methodologically sound, statistically significant, *true*[10]. Instead, we present work that is vulnerable, what March may have called foolish [134]. Our hope is that our drop in the ocean of human knowledge can be, in its utter insignificance, flavourful.

At this point, some might conclude that this work, with all its indulging in the humanities and the social, is not even science.

Well, if so, let it at least be literature.

[10] At least, until it is falsified. But if our work loses significance, are we implicitly condemned to irrelevance?

1.4 List of Contributions

The following publications have been authored in the months just before the beginning of the PhD programme. They are included here because of their relevance to the work we present:

- M. Bonifacio, **L. Angeli**, and M. Stoycheva, 'Enacting Divergent Learning Dynamics in Teamworking: the Case of Technology Battles', in EduLearn17 Proceedings, Barcelona, Spain, Jul. 2017, pp. 6244–6253. doi: 10.21125/edulearn.2017.2416.

- M. Stoycheva, M. Bonifacio, M. Marchese, M. D. Klabbers, M. Ilieva, G. Pisoni, **L. Angeli** and A. Guarise, 'Developing Engagement Strategies in the Blended Learning Triangle: the Case of I&E Education in the EIT Digital', in EduLearn17 Proceedings, Barcelona, Spain, Jul. 2017, pp. 6254–6261. doi: 10.21125/edulearn.2017.2418.

The following publications have been authored during the PhD programme:

- **L. Angeli**, F. Fiore, A. Montresor, and M. Marchese, 'Designing a Hands-on Learning Space for the New Generation', in Proceedings of the FabLearn Europe 2019 conference, Oulu, Finland, 2019, pp. 1–3. doi: 10.1145/3335055.3335060.

- **L. Angeli**, M. Stoycheva, F. Fiore, A. Montresor, and M. Marchese, 'A Conceptual Exploration in the Intersection of Crafts, Technology and Academia for Sustainable Job and Skills Development in the 21st Century', in EDULEARN19 Proceedings, Jul. 2019, pp. 7374–7378, doi: 10.21125/edulearn.2019.1764

- M. Marchese, **L. Angeli**, M. Ilieva, Y. Huang, A. van de Ven, A. Pina Stranger, B. Palm and K. Fobelets, 'C-EXTENDED: Extending the

Erasmus Experience Beyond Mobility', in EDULEARN19 Proceedings, Jul. 2019, pp. 4053–4061. doi: 10.21125/edulearn.2019.1030

- **L. Angeli**, J. J. J. Laconich, and M. Marchese, 'A Constructivist Redesign of a Graduate-level CS Course to Address Content Obsolescence and Student Motivation', in Proceedings of the 51st ACM Technical Symposium on Computer Science Education, Portland OR USA, Feb. 2020, pp. 1255–1261. doi: 10.1145/3328778.3366910.

- **L. Angeli**, M. Luca, C. Grossi, F. Fiore, A. Capaccioli, A. Guarise, M. Stoycheva and M. Marchese, 'Prove Me Wrong! How Debating Becomes the Secret Weapon to Teach ICT Students Innovation and Entrepreneurship', in 2020 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE), Takamatsu, Japan, Dec. 2020, pp. 173–180. doi: 10.1109/TALE48869.2020.9368481.

The following publication is under redaction, and might be submitted before the thesis' defense:

- **L. Angeli**, M. Stoycheva, and M. Marchese, 'Five Tales from the Pandemic: creating safe spaces in online education'. Tentatively to be submitted to "Computers & Education" (Elsevier).

Chapter 2

The Human

2.1 Introduction

Common stereotypes see a computer scientist as a highly competent engineer with low social skills. In stark contrast to this, however, workplace demands for CS professionals increasingly ask for non-technical competences [83].

> As repetitive jobs get automated more and more, the added value of a worker shifts to those parts of themselves that cannot be automated — in other words, to what makes them *human*.

But if it is so, where is this "Human" side being cultivated, during the education of CS professionals?

CS curricula have integrated some non-technical subjects for a long time, but these subjects have always maintained an extremely marginal role [86]. This trend began to shift after the 2009 economic crisis, with more and more Higher Education Institutions (HEIs) trying to follow the wake of the refreshed Silicon Valley scene.

As leading engineers of promiment companies became public figures[1], the world saw the rise of another archetype: the engineer-entrepreneur,

[1] To name the most obvious: Mark Zuckerberg, Elon Musk, Sundar Pichai, Jeff Bezos, etc.

the brilliant (typically white male) "techie" that was able to build a mega-corporation from nothing thanks to their technical talents.

What we now call Innovation and Entrepreneurship (I&E) education is the contemporary attempt by the Higher Education (HE) system to explicitly create this archetype of engineer. Beyond economic growth, I&E education represents an effort to cultivate "the Human" side of CS professionals — hence the name of this chapter.

I&E is not a well-defined discipline or research field. It is a serendipitous aggregation of disciplines, industries, research fields, and practices. To use the vocabulary that we consolidated in this thesis, it is a garbage-can-like ambiguous space. To visualise this idea, we propose the "word cloud" in Figure 2.1.

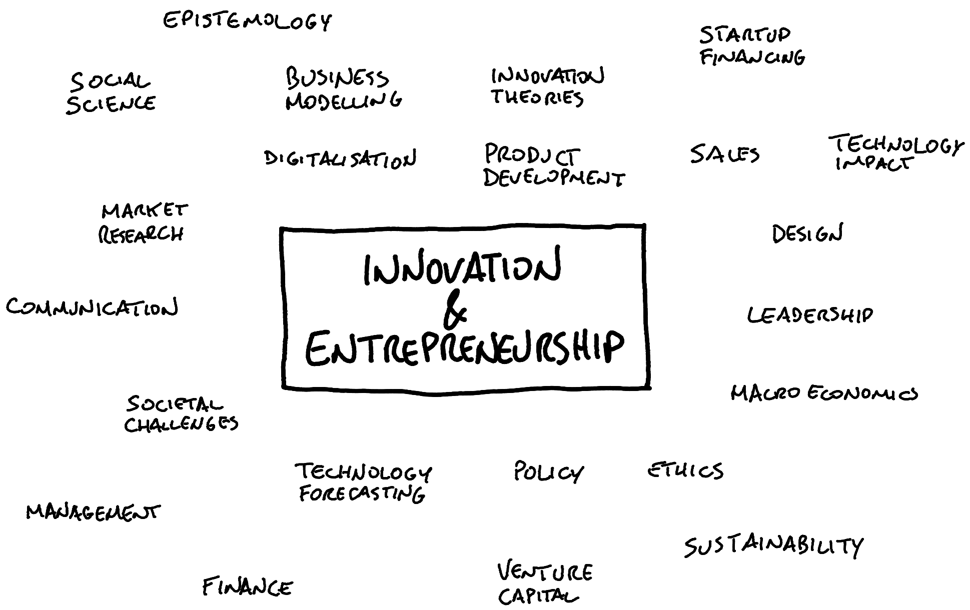

Figure 2.1: A chaotic arrangement of some topics discussed in I&E.

Another way to look at I&E as a discipline is to use the lens of Bernsteinian sociology of knowledge [26]. Drawing a parallel to the work done by Hordern [105] and Bernstein himself in describing the sociology of education, we can wonder how I&E could be inscribed in the framework that describes disciplines through the “discourses” built around them.

Much like in the case of education, one cannot help but wonder whether I&E is able to organise knowledge effectively (in a form of so-called vertical discourse) or instead, with its situatedness and overwhelming presence of tacit knowledge and oral tradition, I&E is unable to do so, becoming what Bernstein calls a horizontal discourse. One could argue that I&E forms a vertical discourse that draws from multiple disciplines, a “segmented” knowledge structure. The strong entanglement between I&E as a discipline, its non-academic practice, and policy, however, reduce the representational power of I&E’s theory base, making the discipline turn to practice-sharing as its main epistemological mode.

Another part of Bernstein’s framework, the classification of disciplines in singulars, regions or generics, is also useful to discuss I&E. Under this perspective, it is clear — starting from the very name! — that I&E shows, at the very least, the features of a region formed by Innovation *and* Entrepreneurship. If we advance our ontological inquiry by one recursive step, discussing the nature of Innovation on the one hand, and Entrepreneurship on the other, we find ourselves — especially on the Entrepreneurship side — in front of yet another discipline that is segmented, if not yet another horizontal discourse. In Entrepreneurship, by far, theory leaves most of its space to practice.

This compounds the challenge of formally describing I&E. Many I&E lecturers are entrepreneurs themselves, practitioners with substantial field experience, not always with academic backgrounds. The field of I&E is nonetheless rooted on influential work and research, such as seminal work by Alex Osterwalder [164], Clayton Christensen [48], Steve Blank [29] and more. All of these authors can be classified both as academics and as entrepreneurs.

Much of the “bleeding edge” in I&E, as a consequence, lies in informal business books, blog posts, knowledge bases of consultants or venture capitalists, practice-sharing sessions conducted in startup ecosystems, and even undocumented oral tradition. Work in the field is often anecdotal, and not consolidated as a cohesive body of literature.

In spite of its non-academic status, nonetheless, work that describes entrepreneurial practice can be well-structured, and summarise effectively what are the main components that contribute to the field's "state of art".

As a sign of our commitment to this view of I&E as a practice, we want to highlight the work of a practitioner, Gary Schöniger, working in the field of entrepreneurial training[2]. In a personal email exchange about yet-unpublished work, Gary shared with us his definition of "Entrepreneurial Mindset" — and, by extension, of entrepreneurial practice.

> *After more than two decades of interviewing entrepreneurs and studying the research in cognitive, behavioral, and social psychology, a new theory has emerged, one that not only reveals the methods and processes that enable entrepreneurs to recognize, evaluate, and actualize opportunities, but also explains the subtle, underlying causes — both within the person and the situation — that drive their behavior. I refer to this as Entrepreneurial Mindset Theory (EMT).*
>
> *EMT posits that non-entrepreneurial behavior is learned, and that while not everyone may want to start a business per se, we are all born with an inherent proclivity to be innovative and entrepreneurial - that is we all have an innate desire to solve problems, to be engaged in work that matters, to have control over our day-to-day lives, and to see our efforts lead to a pathway towards a more meaningful and prosperous life.*

[2]Gary is the CEO of ELI, the Entrepreneurial Learning Initiative, that can be found at `https://elimindset.com/`

> *The desire to fulfill human needs through our own effort is a powerful innate motivating force. It is indeed part of what makes us human. As such, EMT assumes that the entrepreneurial spirit is the human spirit, it is not just in some of us, it resides within us all, and that the development of entrepreneurial attitudes, behaviors, and skills is largely dependent upon social, environmental, and situational factors rather than dispositional traits.*
>
> *Moreover, EMT postulates that the cultivation of these inherent tendencies is necessary, not only to adapt and thrive in a rapidly changing world, but also for economic prosperity and psychological well-being.*
>
> *Entrepreneurial Mindset Theory supports a humanistic view of entrepreneurship — one that affirms the ability of ordinary people to think critically and creatively, individually and collectively, to rise above their circumstances, to solve problems, and to better their world.*

This short note summarises quite effectively many of the inspirations and challenges of the I&E space. To name a few: its experiential dimension (*two decades of interviewing entrepreneurs*); the variety of research that inspires it (*cognitive, behavioral, and social psychology*); its social ambitions (*our efforts [...] towards a more meaningful life*); the emphasis on "soft skills" (*think critically and creatively*) and its optimistic, sometimes positivistic, attitude (*to solve problems and to better [the] world*).

In 3.2.1, we will discuss more extensively the idea of knowledge obsolescence. Since our goal is not only to teach about innovation, but also through innovation, we need to take into consideration the length of the cycle that leads to a theory, and its teaching method's, consolidation as a research result.

Jandrić [112] very effectively summarises the process behind the publication of a peer-reviewed article, highlighting many of the critical points behind the consolidated process and potential ways out. Critical points range from the explosion of potential publication venues, to opaque and tortuous review processes, to problems in the business model of academic publications.

The time and visibility dimensions, however, are among the most problematic for I&E: indeed, if an article's publication cycle stretches through many months (and years for visibility), some of the insights contained in it might already be outdated by the time when the article is circulating!

If we hope to understand the I&E space, our approach is to break it down in its components, and try to see what each of these includes. When necessary, we will also try to back-track to the "raw" source — namely, practice. To give a sense of how this space is ill-defined, we will take each macro-area of I&E (so, 1. innovation; and 2. entrepreneurship) and provide a few examples of active curricula taken from prominent HEIs offering I&E education.

The "Innovation" label variably includes innovation theory, epistemology, social sciences, macroeconomic theory, product development, design, technology forecasting, etc.

"Entrepreneurship" instead includes elements of business administration, business modelling, economics of startups, soft skills, market analysis, etc.

The goal of this work, however, is not to define and document what is or is not I&E, but to discuss why it can be valuable for CS students, and how it can be taught.

We have presented in 1.2.3 our general principle for the design of pedagogical methods: teaching methods should reflect how the subject-matter is practiced in the world. As I&E is inextricably intertwined with entrepreneurial practice, we need to look at how innovators and entrepreneurs navigate their environment, and design our teaching methods accordingly.

As a first step, we should notice that I&E is not only about its content: successful entrepreneurs are not (only) the best-trained professionals in their field. I&E is as much about content as it is about *mindset*. Formal research in this direction is still at a very conceptual stage, often referring to work such as Bandura's theory of self-efficacy [20] [19].

A large part of I&E education taught within universities, as a consequence, tends to focus on consolidated practical or theoretical knowledge in the field. In plain words, it aims to provide students with a toolkit, rather than growing a mindset.

In the great challenge that is to formally define a mindset, the actions we propose for I&E in the space of this thesis attempt to bypass the problem.

> If we agree that entrepreneurship is rooted on a mindset, and that HE can provide the toolkit, we propose to embed the mindset in the pedagogy rather than in the content.

In this chapter, we pursue the opportunity to transform a learning space that aims to *teach about* entrepreneurship in one that aims to *practice* entrepreneurship while learning about it. The highly inductive nature of I&E seems to favour this logic: the sooner one starts practicing, the stronger the basis of their induction will be.

As a consequence, we have developed some teaching and learning methods that attempt to replicate the main fixtures of the "real world" I&E environment in the classroom. In the instantiations and reflections that we will present, we will propose a model of teaching and learning where knowledge is built through informal sharing and debating; teachers take the role of mentors and coaches; students always work in teams of different competences; and mistakes and contradictions are not only tolerated, but welcomed.

In the rest of this Chapter, we will present the interventions that we have carried out in the past years.

Our Main Story, presented in 2.2, will describe Problems, Solutions and Participants that rise from implementing I&E courses and making them part of the mainline curriculum of CS students.

We will then discuss, in our Side Story (2.3), some I&E courses that are constrained in nature. We call them I&E experiences, and in this Side Story we will discuss the challenges we face in designing relevant learning spaces that keep the goal of creating a change in mindset, and not only imparting content.

2.2 I&E Mainline Courses

Before diving into our Garbage Can of Problems, Solutions and Participants, we would briefly like to define what we mean when we talk about "Mainline I&E courses".

The experiences we describe in this section have been carried out in the context of two courses. Both are part of the main path of the EIT Digital Master School I&E Minor, which we outline in more detail in 2.2.3 and in 4.2.1.

For now, we just wish to introduce the two courses:

1. I&E Basics → a first-year Master's course that serves as the introduction to I&E.

2. I&E Studies → a second-year Master's CBL course that serves as a "capstone project" in I&E.

Both courses have a long legacy at the University of Trento. As of the time of writing of this thesis, they have been performed for some 8 editions, and the main author has been involved in the teaching of 4.

The I&E Basics course is designed to be the students' first approach to I&E. Our university has historically made the choice of asking all students in the CS and Communications Engineering Master's to attend the I&E Basics course. Only on the last Academic Year (2020/2021) has the course been split in two, keeping EIT Digital students separated from non-EIT CS and Communications Engineering students.

The course has been the main research focus of the I&E work conducted in this thesis, and has been the testing grounds for many teaching methodologies. The corse underwent a forced transition from a blended mode (mostly in-person, with substantial online material to support it) to an online-only course during the COVID-19 pandemic[3]. This disruption has been used as a chance to rethink the course's teaching methods, using the pandemic as an opportunity for reflection and growth. By following the course's published history through the instantiations (mainly 2.4.1 and 2.4.2), the reader can understand how deeply this course evolved, while remaining rooted in its general philosophy, that we describe in 2.2.2.

The I&E Studies course also radically evolved, from a "minor thesis" capstone project, to a 2-in-1 blended course, to a distributed CBL course. It has been at the center of a network-wide redesign exercise by the whole EIT Digital consortium, and some of the results of this experimentation have been published by a non-inclusive subset of the network's teachers in various venues.

2.2.1 Problems

We want to start this Story with an informal anecdote. Every year, we open our I&E Basics class with a small game of free association around the words "innovation" and "entrepreneurship".

When asked to associate around "innovation", a vast majority of the students propose a variation of "something new". Freely associating starting from the world "entrepreneurship", instead, usually elicits different answers — quite interestingly — based on the language used for the game.

When students freely associate to the word "entrepreneurship" or "entrepreneur" in English, most of the answers tend to gravitate toward "confidence", "vision", "passion" and the likes.

[3]During 2020 and 2021, many world governments have mandated education at various levels to be conducted online. The spreading of the virus causing COVID-19 was proved to be linked to indoor person-to-person contact. The Pressure on the education was extremely high, with many teachers scrambling to adapt their teaching to this new setting. As of the end of 2021, scientific literature in the field of education is saturated with reports of what happened during 2020 and 2021. Future readers interested in gathering historical hindsight about this phenomenon should find it easy to get a sense of the scale of what happened by reading publications from this time span.

Our classes, however, usually have a sizeable Italian minority, so we ask Italian-speaking students to associate around the translated "imprenditorialità" and "imprenditore". When those same students associate to the Italian equivalents, answers tend to gravitate around "money", "profit", and even "Berlusconi"!

In spite of its informality, this anecdote gives a tangible example of one of the key problems faced in the practice of I&E education:

> When we talk about "innovation", "entrepreneurship" and other such concepts in the space of I&E, students already have their interpretation of what these words mean.

As we discussed in the Introduction to this Chapter (2.1), I&E is not a single discipline, but a serendipitous aggregation of a variety of disciplines and fields. Furthermore, the I&E field is rooted on many practices rather than on formal research: these practices mean that I&E jargon is also ill-defined, borrowing words from all the disciplines it draws from. Most interestingly (and what can potentially make matters even more confusing), I&E integrates in its language many buzzwords, or other words of common use.

When these words of common use are integrated in the I&E space, however, they usually take specific meanings. To give a slightly more formal example, words such as "risk", "uncertainty" or "ambiguity", have intuitive meanings in the common language, and a different, very precise meaning in innovation theory [119] [135].

This overload in meaning creates an extra challenge for the teaching of I&E:

> In I&E education, not only do students have to *learn* new concepts, they also need to *unlearn* their previous understandings.

Processes of unlearning are still debated as to their framing [90]. Even with the controversy surrounding them, however, there seems to be an agreement on the fact that that unlearning takes substantial effort to be accomplished, some argue even more so than learning [31].

The ambition of I&E to teach a mindset rather than impart content compounds the issue. Producing a change in mindset — even in its simplest form of a change of habits — is a long-spanning process and it requires, on the side of the learner, a constant, focused effort [165].

Achieving a meaningful change is even harder when we consider that the space given to I&E education in CS curricula is extremely limited, even in privileged contexts such as the EIT Digital Master School I&E Minor.

Most, if not all of the disciplines that fall into the I&E space are very much unlike what most CS students are normally exposed to: economics, business administration, organisation science, decision theory, epistemology, law, social sciences... All of these ample research fields have their own practices, traditions, language and methods, that differ sometimes radically from those used in CS.

As a concrete example, we can look at how some of these disciplines store their knowledge, and how that knowledge is exchanged: law may use codices and precedents; social sciences qualitative methods; decision theory logical proofs. The CS student approaching I&E faces the gargantuan task of entering an alien, ill-defined space and proficiently navigating it — in no time.

Finally, we want to briefly discuss the interactions between participants: CS students are used to a culture of tinkering, producing and making sense of documentation, while most of the I&E knowledge is not systematised, and discussed orally, in blogs, or in informal business books. This is reflected in the student-teacher interaction: I&E tends to rely less on formal lectures, and more on direct interactions, such as through mentoring. These

Discipline	**Main Knowledge structuring method**
Economics	Academic research (often quantitative)
Management	Practitioner books
Social Sciences	Academic research (mixed methods)
Marketing	Informal documents
Philosophy	Treatises, papers, books
Business	Practitioner books
Policy	Policy papers

Table 2.1: A few disciplines in I&E and their main ways to create and expand knowledge.

ways of interacting between students and teachers are quite different from those students are used to in technical courses.

Managing these relationships represents another of I&E education's main challenges, but also a resource. As we transition towards the space of solutions, we ask ourselves the question: how can we effectively tackle all these problems?

2.2.2 Solutions

Our general approach to the teaching of I&E is rooted on a few key intuitions. As the research field in I&E education is so new, many of these have not been formally measured in the field. A significant part of our work (and contribution to the state of art) consists exactly in outlining and structuring these general principles, and providing some first proofs of concept that these principles warrant further formal exploration.

While we will discuss these in more detail in the Instantiations (2.4), they can be summarised in this way:

> Properly and deliberately shaping *how* a class is taught (its pedagogical methods) can be a powerful tool to make *why* the subject is relevant and *what* its content is more apparent to students.

If we use our ANT lens, we can see pedagogical methods as a practice, and previous social research has already argued for practices as non-human actors that can embed designer's intent [126]. As we are teaching in and about an ambiguous environment, then, we have the opportunity to shape our practices so that they assist in the delivery of our content.

Seminal work in the field of design started by Don Norman defines what he called "affordances" [154], which are how a designed object suggests how it is supposed to be used. Much like the designed affordance of a physical object, pedagogical methods can provide learning affordances — a teaching method can suggest to learners *how they can learn*.

Lectures, in their historical context, did this quite effectively: lecturers read text to an audience of students, who transcribed it. Learning, in that context, was tied to *access* to knowledge: being able to *read* it and *transcribe* it.

The last decades, however, have created a substantially different knowledge landscape: the challenge is not to access knowledge, but to *critically evaluate* it [167] [82]. If the leading learning method, however, remains tied to lecturing, it is quite clear that we are losing an opportunity — for a CS student approaching the I&E space, making sense of such a different field becomes all but impossible.

Designing appropriate pedagogies, therefore, can make solving the problems discussed in the previous section a tractable challenge. I&E sees entrepreneurship as a practice and as a mindset — if the mindset cannot be effectively taught by lecturing, then a possible way to teach it is through practice, embedding it into the class' pedagogical backbone.

Reshaping the class' structure starts from a redefinition of how students and teachers relate with each other: for example, I&E tends to see the involvement of many teachers that do not have an academic background. A substantial inclusion of practitioners in I&E's teaching body signals to the students that I&E education behaves differently from what they are used to, facilitating the change in teaching methods.

But what are these different teaching methods, why do we argue that they are relevant for I&E, and what do they allow us to achieve?

The "I&E Educator's Toolbox"

If CS comes from a long legacy of mathematical proofs and engineering benchmarks that leads to an objectivist world view, I&E is a space where contradiction is sought and welcomed.

The sociological and philosophical roots of I&E education make this a field where there almost never are right or wrong answers, but where one has to take a stance navigating a vast number of ill-defined trade-offs.

One of the general Learning Objective (LO)s of I&E is then to learn to discover and recognise these trade-offs, and analysing the possible outcomes.

The main tool that we have experimented with is that of debating. We go deeper in the analysis of debating as a pedagogical tool in 2.4.1, but our main addition to the state of art in debates-based pedagogy is the inclusion of scenario-building 2.4.2 as a way to discuss key trade-offs.

Philosophy has a more than millennial tradition of using thought experiments to discuss trade-offs, and famous thought experiments are at the basis of science, used by the likes of Newton and Galileo. Speculative thought has, however, had limited space in CS education, even though CS advances have inspired the writing of countless writers of fiction and non-fiction.

Our introduction of scenario-based debates in the context of I&E is a fundamental bridge to bring CS students in the I&E domain. Many CS students are at least somewhat familiar with the basic premises of science fiction, and most of them have engaged, even naively, in speculating about the future impacts of technology.

Debate Scenario	Technical Theme	I&E Theme
Should future performance sports feature cyborgs and robots?	Advances in robotics / human-machine integration	Spectacularisation of society
Should future humans live in "smart cities" or "smart countrysides"?	Climate impact of technologies	Green technology
Should copyright law favour protecting platforms or content creators?	Social media and platform economy	Intellectual Property and Copyright
Is the "gig economy" a change for good or for bad?	Effects of platform-isation of work	Digital Transformation of business models

Table 2.2: A mapping showing examples of how debate scenarios can be used to bridge CS students to I&E.

Scenarios can be used to at the same time mask and exacerbate existing challenges in the social, economical and ethical domains. As these scenarios are built by teachers starting from broad global challenges, we can even argue that they represent the first step in a CBL process [132].

CBL, not without its controversies [133], has been another key pedagogical method that we used in the I&E space. By showing students how what they are learning in the class can be immediately applied to solve real-world challenges, we can reinforce the role of I&E as a practice.

Navigating these challenges, which can be characterised as complex socio-technical systems [178], however requires a form of structured guidance that students can rely on. The solution we propose is that of relying on a shift in the student-teacher relationship in the form of mentoring.

Mentoring has been proposed as one of the ways to change traditional student-teacher relationships [53]. At the core, it represents a shift of the role of the teacher from a figure of authority to one of experience, serving as a facilitator of the learning process. Figure 2.2 visualises this shift in roles, with the Lecturer taking the role of a Mentor.

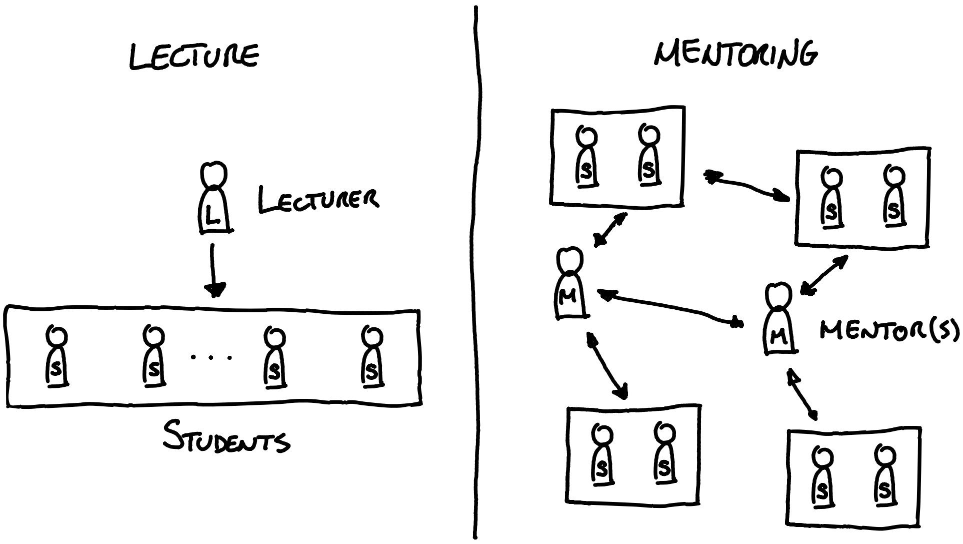

Figure 2.2: A simple diagram visualising the transition between a Lecturing-based and a Mentoring-based class structure. The Lecturer, on the left, becomes a Mentor, on the irght. Interactions between groups of students are always assumed to be bi-directional.

Student-student relationships can also be changed: while the shift to online learning allows us unprecedented new opportunities for collaboration, team work needs to be structured (or scaffolded) [85] to ensure that the additional complexity of the new collaboration contexts does not compound with the complexity which is already present in the transition of CS students in the I&E space.

The two fundamental tools that we have experimented in this sense are the use of *student roles* and the creation of *buffers and "safe spaces"*.

Our experience of assigning roles to students has been expanded in many different directions, from tasking students to help teachers in taking care of organisational practicalities needed to smoothly run courses, to suggesting internal management structures to the students to facilitate their collaboration.

Engaging students in the class' management is an invaluable tool in promoting a co-creation mindset of learning experiences [188] and establishing a relationship of mutual trust between students and teachers. The suggestion of division of roles internal to student teams when they engage in group work, then, serves as a channel to mirror the general class' structure, and avoid situations of "free riding" [23].

Finally, we devoted a significant effort in creating "safe spaces" for students in terms of evaluation, social interaction, and class time. Table 2.3 shows the evaluation structure of a course (our 2020 I&E Basics) featuring ample safe spaces.

Task	**Max marks**	**Pedagogical Role**
Peer-assessed short essay on DT	2 (+ 1 for performing peer assessment)	"Ice breaker", interaction and feedback between peers. **(Safe Space)**
Peer-assessed exercise on a chosen I&E tool	2 (+ 1 for performing peer assessment)	Practice of specific I&E competences. **(Safe Space)**
Group essay combining a number of practiced I&E tools	10	Assessment of collaboration and I&E competences.
Individual presentation	20	Assessment of soft skills and I&E competences.

Table 2.3: Buffers and "safe spaces" in the evaluation structure of an I&E course. The maximum score for the course is "30 cum Laude", achieved by scoring over 30 marks.

We employ safe spaces not as a therapeutic tool [101], but rather as a way to prevent stress and facilitate learning. As we discussed in 2.2.1, the unlearning process is more cognitively taxing than learning. Safe spaces become a way to embed in the class' structure the idea, typical of the entrepreneurial mindset, that failure is a fundamental step for success.

A class setup including safe spaces is one that truly encourages making mistakes, iterating over one's ideas, and privileging actions — all of which are desirable qualities for innovators and entrepreneurs.

Skills development in I&E Education

Having defined pedagogical methods, we now move on to discuss those less tangible Learning Objectives (LOs) that define attitudes and abilities that we aim to develop in students of I&E.

Many frameworks and policy documents attempt to define and measure these attitudes. Each of them excludes or includes one of these aspects and gives a different name to the whole system. For the sake of simplicity and clarity, in this document, we will call these attitudes "soft skills".

While this is possibly the most generic term, none of the existing frameworks provide persuasive arguments (and far less, evidence) to support the adoption of one's taxonomy over another's. To use Latour's words, this seems to still be an open debate [124].

While still an open debate, soft skills have been for a long time at the forefront of many pieces of educational policy within and outside Europe. Skills have been addressed in their relevance to engineers as far back as the "Engineering Education for the 21st Century" address to the National Science Foundation in 1998 [66], and more recently in the ACM and IEEE-CS 2020 Computing Curriculum [2].

In Europe, the connection between soft skills and entrepreneurship was explicitly addressed in many Communications of the European Commission, including those that established the EIT as far back as 2006 [58], and more recently in the EntreComp [18]. Recent frameworks such as DigComp [45] also feature some skills that are typical of entrepreneurship, though under a "digital" angle.

The OECD Centre for Educational Research and Innovation also largely investigated the development of soft skills in higher education, producing reports such as [16] that showcase the need for soft skills in many industries and areas of our economy.

As said before, skills and competences frameworks variably include or exclude certain skills. What they do agree upon, however, is about the relevance of these skills. Table 2.4 shows a mapping between skills in the World Economic Forum's latest "future of Work" report and the two European skills framework mentioned above: DigComp and EntreComp.

The table should highlight how skills frameworks, in our case exemplified by those of the JRC, respond to a market need, and how the area of I&E, especially when connected to digital education, covers an overwhelming majority of these skills.

Furthermore, soft skills can be arranged in a general hierarchy that ranges from a "low level" involving the execution and implementation of work, to a "high level" including forecasting and strategy.

"Future of Jobs" (WEF)	**DigComp (EC/JRC)**	**EntreComp (EC/JRC)**
Analytical thinking and innovation	Identifying needs and technological responses	Spotting opportunities; valuing ideas
Active learning and learning strategies	Information and data literacy (competence area)	Learning through experience
Complex problem-solving	Solving technical problems	N/A
Critical Thinking and analysis	Identifying needs and technological responses	Ethical and sustainable thinking
Creativity, originality and initiative	Creatively using digital technologies	Creativity
Leadership and social influence	Collaborating through digital technologies	Mobilising others
Technology use, monitoring and control	[most]	N/A (mentioned occasionally)
Technology design and programming	Digital content creation (competence area)	N/A
Resilience, stress tolerance and flexibility	N/A	Motivation and perseverance; coping with uncertainty, ambiguity and risk
Reasoning, problem-solving and ideation	Problem Solving (competence area)	Spotting opportunities; vision

Table 2.4: A comparison between skills taxonomies, showing how, though sometimes under different names, there is a widespread interest in "soft skills" both under an industry and policy level.

This distinction between low and high level is a recurrent metaphor: it is also used in the CS field to informally taxonomise programming languages and, in the education field, to classify learning outcomes ([10]).

I&E tends to focus more on high level skills. To make the discussion more tangible, we will now outline a few such skills and how they can be developed in and through I&E education. For the sake of practicality, we will make the choice of aligning with the framework that best fits the context in which we have been operating: the EIT Overarching Learning Outcomes (OLOs).

EIT OLOs are not a skills framework in a strict sense but nonetheless they can be used as a guidance to see what are the skills EIT wishes to develop in the participants of their programmes.

A frequently-discussed skill is that of *critical thinking*. In a tradition that we can lead as far back as to the 1800s with work by Kant, critical thinking refers to the systematic analysis of facts and circumstances in order to find their limits.

Included in all of the frameworks and taxonomies we analyse, critical thinking is seen as a key asset in navigating the contemporary and future knowledge space, defined by the challenge of *assessing* knowledge rather than *accessing* it. I&E, through appropriate pedagogical strategies, can address the need to develop critical thinking in a variety of forms.

Frameworks for idea exploration and discussion (even simple ones such as Don Norman's "Yes, but, and" brainstorming methodology [153]) give an example of critical thinking in action: statements and ideas are evaluated in terms of their potential to be extended and of issues they present. What are arguably other forms of critical thinking are those labelled as systems thinking [115] or systems intelligence [109].

Creativity is another frequent member of many skills taxonomies. EIT directly includes creativity as one of its OLOs and defines it — at the Master's level — as "The ability to think beyond boundaries and systematically explore and generate new ideas."[4]. The teaching of creativity is yet another open debate. While there are many proposed methodologies (of varying scientific effectiveness), there seems to be a consensus about its importance.

We argue in this context for the need of *constrained* creativity (the

[4]See OLO 3 at `https://eit.europa.eu/our-activities/education/eit-learning-outcomes`

"systematic" dimension mentioned in the EIT OLO 3). As many creative professionals can attest, high-level creative results are often obtained by working with narrow constraints. Those same professionals can be an important asset to be brought in the I&E classroom: as the teaching of I&E is already very practitioner-oriented, creative professionals are less challenging to fit in an I&E class.

In our simple experiences of bringing creative professionals for lectures in I&E classes (including a comic book writer and a theatre director), a strong need, however, became apparent: when out of their normal work and into the boundaries of another profession (that of teaching), creative professionals also need to be mentored by teachers.

Mentoring and collaboration are a broad category of skills that also frequently appear in taxonomies. Presentation, communication, team management, interdisciplinary work, remote collaboration... All of these ideas refer to the need for CS professionals to be better-skilled in how they deal with other humans.

By now, there is also a growing body of evidence that supports the link between suitable teaching methods with the development of skills and long-term retention of knowledge (one can, for example, look at literature reviews such as [104]). The choice of suitable pedagogical methods can become, in this context, an instrumental tool to aid the work of HEIs in forming professionals and researchers that are skilled in a broader sense, and not only technically.

We have highlighted in the previous sections how pedagogical methods can be set up to facilitate interactions between students and with teachers. Ultimately, interpersonal skills are more than any other skill developed through practice. The role of the teacher in developing this skill is fundamental: if we agree that teachers can and should be role models for their students, then they should lead by example in establishing good interpersonal relationships. I&E education, again being rooted in practice, has the opportunity to be a prime space for the development of good interpersonal skills.

As our last step, we want to discuss what is called in the EIT OLOs "ability to form value judgements", which ultimately refers to ethics. Ethics is a woefully undeveloped and unexplored area of CS, with only an extremely limited minority of curricula dedicating time to discuss ethics [181].

Technological policy is, however, quickly catching up to increasing pressure to include ethics in the global discourse. Recent work such as the EC's Data Strategy [59] [60] or the German Data Ethics Commission's report [55] show how the extreme growth of global innovators such as big tech companies are the reason why innovators and engineers need more ethical competences — and we argue it is the duty of I&E education to provide them.

But, with all these ambitions and solutions, how are the participants — the students — positioned?

2.2.3 Participants

For our description of the Participants, we think it is appropriate to start from the context where our students come from.

In Mainline I&E courses, we are teaching, for the vast majority, students of the EIT Digital Master School. We describe how the EIT Digital Master School works more in general in 4.2.1, but we briefly summarise it here.

> The EIT Digital Master School is a double degree two-years Master's programme in Computer Science, where students take 90 ECTS in a specific flavouring of CS (the "Technical Major") and 30 ECTS in I&E (the "I&E Minor"). Students take their first year in one European university, and their second year in

another university. At the end of their Master's, students earn three certificates: degrees from each university, and an EIT Label certificate.

A relevant point to discuss is the student selection process: EIT Digital Master School students are selected not only with criteria of technical excellence, but also out of their interest in I&E. Each student, at the time of their application, presents a business idea through some guided questions. This filter should — in theory — separate the EIT Digital demographics from other students in CS since, as we discussed, the general interest of CS students in non-CS subjects is limited.

A first element of evidence that highlights this interest delta is what we call, in 2.4.2, the I&E "interest gap". Fig. 2.3 visualises this phenomenon whereby students' self-reported *a priori* interest for I&E subjects seems to be substantially lower compared to the average of our department. While we do not (yet) have data that separates the EIT Digital and non-EIT Digital demographics, anecdotally, enthusiasm for I&E in EIT Digital students is higher, if still variable.

Another informal experiment that we run every year in our first-year course also tells an interesting story: at least at the beginning of their Master's, a vast majority of students still sees themselves as future employees rather than future entrepreneurs. This information should not be seen as simply discouraging: as we discussed in 2.2.1, students have at this stage a naive intuition of what it means to be an entrepreneur, and what is possible in the space of entrepreneurship. It is our job as teachers to build their awareness, inform them, and grow their views.

As a last note, we want to briefly touch the theme of so-called technological unemployment. In what is yet again a completely open debate, various studies argue that DT is a trend that might make many jobs disappear, or that it might create unprecedented job growth [170] [207].

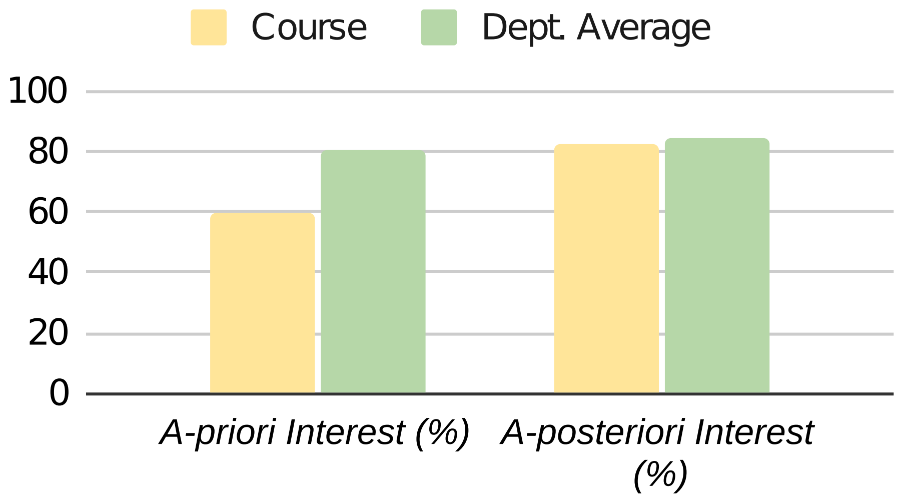

Figure 2.3: The "interest gap" for the I&E Basics course compared to other courses in the department (all of which are technical). The figure summarises one of the main results in one of our articles, namely that appropriate teaching methods can help compensate for lack of interest.

For now, it seems safe to say that it is doing both. DT has for sure redefined what it means to work through always-on connectivity, and accelerators such as the COVID pandemic have provided chances to show how pre-pandemic wisdom about best practices, for example, of work productivity, might be outdated [61].

The most striking case in this sense is that of remote working: remote jobs are on the rise, both in traditional and new job descriptions. In this context, I&E can be seen as a lens through which potential new jobs can be discovered.

As programming jobs — the most frequent career paths for CS graduates — are also foreseen to be eventually obsolesced by technological unemployment, could I&E be an asset to educate CS professionals not to be replaced by machines or, in other words, *remain Human*?

2.3 I&E Experiences

A frequently-cited adage in the business and innovation circles states that "innovation happens at the edges" [48]. If so, it is natural that our work should also seek and experiment at those edges.

> We call "I&E Experiences" those learning activities in the space of I&E that are not full courses, but are part of a University's I&E offering. In practice, these may include curricular activities such as ECTS-awarding Summer Schools, but also extracurricular programmes of varying length and commitment, from pre-accelerators to I&E hackathons.

The experiences we present here are usually self-contained implementations. They do not have the option to rely on a common background on the participants' side and, even when there is such a background, it does not hold a major relevance for the experience's subject-matter. Their compressed nature and mix of backgrounds makes I&E experiences an "edge", where we can nurture opportunities to innovate teaching.

These factors configure I&E experiences as a prime space for pedagogical experimentation: on the one hand, the stakes are usually lower, making students more willing to experiment; on the other hand, their intensive nature exacerbates the need for their message to be conveyed not only through content, but mainly through practice.

An episodic, intensive, or extracurricular format changes dramatically the pedagogical requirements, and amplifies many of the challenges normally encountered in I&E education (see 2.2.1. The role of I&E experiences in our work has been to pilot more radically different pedagogical approaches and to experiment infrastructural solutions. I&E experiences were precious contexts to test our methods outside of their comfort zone, facing challenges such as the need to scale to large numbers, the management of complex logistics, or the deployment in an unfamiliar environment.

The results of experiments carried out in I&E experiences are not typically published. When they are published, the literature often relegates them to poster articles (see, for example, [192], as a formal evaluation of their outcomes would make the implementation, which is the focus, cumbersome.

Yet, in spite of their low publication value, I&E experiences have a high *practical* value — they are frontier developments, the bleeding edge of pedagogical experimentation. In many way, they represent the space where teachers-entrepreneurs can practice the disruptive innovation they are teaching.

In this Side Story, we will present some of our experiments — done both within EIT Digital and outside of it. Each of them represents a possible answer to a challenge in the space of I&E education, and of innovating computing education more in general. Through our exploration of I&E experiences, we want to cement two ideas:

1. That a "process first" design of I&E courses (and of any course more in general) can help to shift the focus of a learning experience from content to mindset.

2. That teaching methods can and should be used as a tool to help educational experiences achieve their LOs.

2.3.1 Digital Transformation Summer School (Ljubljana, 2019)

This Experience refers to a pilot Summer School done in the EIT Digital context. EIT Digital Summer Schools have the peculiarity, as one of our colleagues was fond to remind us, to be more accurately defined as "summer courses", as they award ECTS and are, for students of the EIT Digital Master School, a required course in their I&E minor.

Normally, these summer schools are intensive courses focusing on business development: students work in small teams to develop a business idea in the Summer School's thematic area, which is themed around a key topic in the CS domain[5]. Nonetheless, the EIT Digital specfications are clear: Summer Schools are *I&E* courses, with a technical *flavouring.*

In this experimental Summer School, our goal was to flavour the Summer School around an *I&E* topic, namely Digital Transformation (DT). This was done first and foremost by changing the teaching methods and final deliverables: instead of delivering a pitch for a potential new company, students would work on assisting an organisation's[6] DT process by solving one of their operational or business challenges, and would in the end pitch their proposed solutions. In other words, we piloted a transition of the EIT Digital Summer Schools to CBL.

To narrow down the space of potential challenges, the Summer School focused on the theme of Urban Resilience, with the summer schoool (and the company providing the challenges) being sourced from two locations that face resilience challenges: Ljubljana in Slovenia (a city particularly prone to earthquakes) and Venice in Italy (prone to floodings, and a symbol of climate change).

The summer school's model foresaw a mix of I&E content, a substantial amount of mentoring time, field visits, and ample time for autonomous group work. Students had to immerse themselves in their assigned organisation's context, make sense of their stakeholders, challenges, and practices, and ultimately figure out what would be the most sensible intervention to aid the organisation in their DT process.

[5]Examples of topics in EIT Digital Summer Schools are: "Digital Platforms for Smart Cities" or "Disrupting Finance with Digital Technologies".

[6]Such as a company, an NGO, or a public entity.

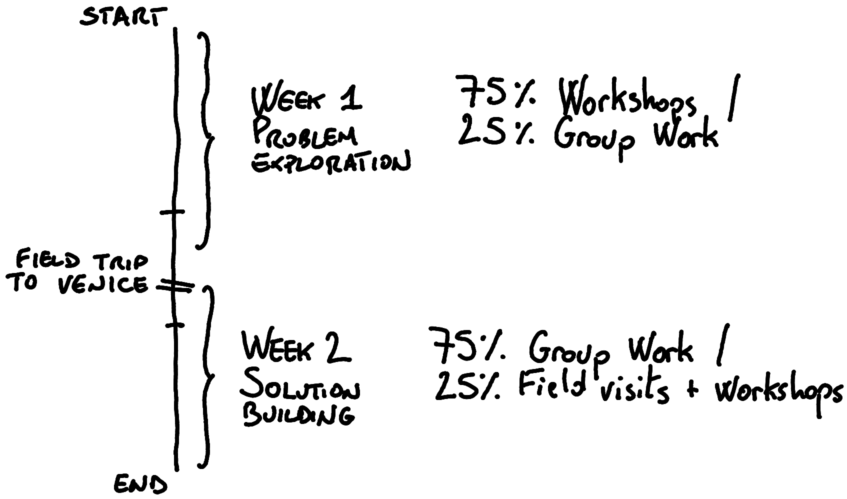

Figure 2.4: The general plan of the "DT Summer School" pilot.

Pedagogically, the summer school asked the students the question: what is your role as both CS and I&E professionals in shaping the DT process?

Creating a space for students to explore potential answers was one of the intuitions that led us to thinking about the idea of "educational safe spaces" (see our discussion in 2.2.2). Additionally, the Summer School was also a chance to keep experimenting with CBL, and to bridge the students in their EIT Digital I&E Minor from the first-year courses, that mostly cover business development, to the 2nd year CBL course, and eventually their industrial internship/thesis.

2.3.2 "There, and Back Again: Mission to Europe" — EIT Digital Master School Kick-Off (Trento, 2019)

Can we deliver a meaningful I&E educational experience in the space of two days, and for more than 400 people? This question was at the base of our design of the 2019 EIT Digital Master School Kick-Off event, involving all first-year EIT Digital Master School Students in a "Business Challenge" lasting two half-days and a full day.

During the Business Challenge, teams of around 5 students are tasked with developing a business idea, and ultimately pitch it to a panel of academic and industrial experts in a "pitching contest" format.

In such a constrained setting, the main need has been to establish what could be a meaningful mindset element that could be conveyed in the experience's short time frame. Our decision eventually converged on exploring Europe's new Framework Programme, Horizon Europe, based on work by economist Mariana Mazzucato [143]. The Kick-Off's Business Challenge prominently featured the Framework Programme's Missions. With this design, we wanted to showcase one of the main principles in Mazzucato's work:

> An entrepreneurial State does not only "de-risk" the private sector, but envisions the risk space and operates boldly and effectively within it to make things happen.

The Business Challenge's name takes inspiration from the idea of "missions" as a journey of fellowship, quoting in its title J.R.R. Tolkien's "The Hobbit".

As the Kick-Off is one of the first steps of the EIT Digital I&E Minor, our goal was to pass the message from the beginning that entrepreneurship is not just a matter of venture creation, and that digital entrepreneurship specifically needs to combine competences from many fields of knowledge. We wanted to showcase how — especially in the European context — entrepreneurship is a matter of social responsibility [28], commitment to sustainable development, and interdisciplinary work.

The structure of the Business Challenge (see fig. 2.5) embeds these reflections. Each team of students is assigned to develop their entrepreneurial idea in the space of one of the Horizon Europe Missions. The teams, grouped in batches of five, are assigned one Senior Coach and two Junior Coaches to help them their task. Coaches lead their assigned teams

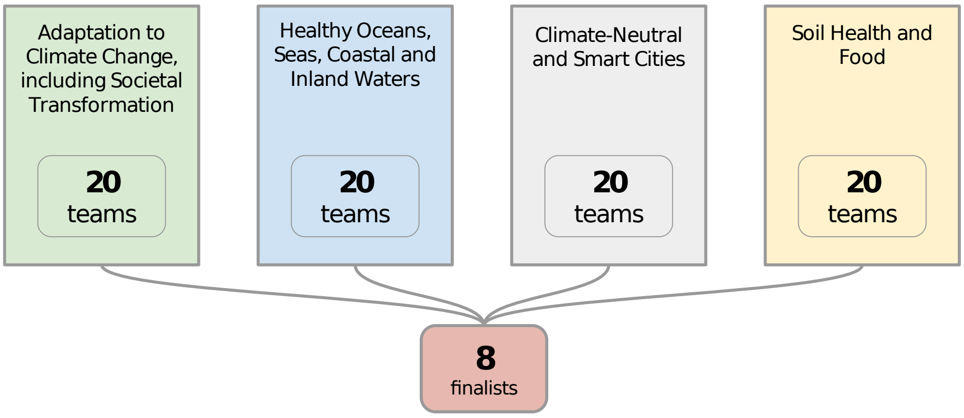

Figure 2.5: The general structure of the EIT Digital Master School 2019 Kick-Off Business Challenge.

through a structured process of idea development, using a "constrained creativity" approach as described in 2.2.2.

The Business Challenge was divided in two main phases: a "diverge" and a "converge" phase, following models proposed by Don Norman [153], and that we also explored in our 2017 work 2.4.1. This, once again, is rooted on the idea of "There, and Back Again": students first engage in the speculative exploration of a plausible future (going "there" in what could be also called an act of prospection [186]), and then bring their vision back to reality ("back again", through an act of collective sense-making [234]).

To aid in the tasks proposed in the Business Challenge, we developed a simple business modelling toolkit, including an adaptation of Osterwalder's Business Model Canvas [164] and a custom-made tool to identify value propositions (an amply simplified version of the Value Proposition Canvas [163]). As the Business Challenge targeted neophytes in I&E, one of the canvases was designed following a fantasy metaphor, with the goal of reducing jargon overload.

A large effort was also dedicated to setting up appropriate processes for the Business Challenge's management, from preparation to debriefing, and in making sure that all key stakeholders (including, for example, the EIT

Figure 2.6: One of the “canvases” developed for the Business Challenge. Notice how it makes use of metaphors rather than directly introduce business modelling jargon.

Digital Alumni foundation) were well-represented and empowered in the process.

The key lessons learned from the execution of the Business Challenge are two:

First, it highlighted the critical importance of so-called Information Architecture [64] when attempting to achieve scalability in a non-lecturing educational context. While the literature amply discusses scalability as a problematic dimension [7], to our knowledge no research discusses the implementation of a precise information architecture as a potential solution to this challenge. Our experience in this context, also observing other similar initiatives, is that adding staff is not the solution to these woes, and a more thorough approach is required.

Second, the Business Challenge highlighted the potential of pedagogical design as a way to open additional channels to deliver students content and mindset. From brainstorming methodologies to structured speculative

Pedagogical Element	Content Element
Mission-based theme	Missions of the EU's Framework Programme
Diverge / Converge structure	Idea generation and refinement process
Multiple pitching rounds by different stakeholders	Review processes
Simplified "canvases"	Introduction to Business Modelling

Figure 2.7: A mapping between some pedagogical elements in the Business Challenge and relevant content elements.

thought, to effective presentation, properly-designed educational methodologies can serve as a way to dramatically increase the information density of a learning experience by increasing the available channels. This intuition can once again be rooted on our discussion of ANT, whereby we can see each method as an actor embedding an intent.

2.3.3 Beyond Pre-Accelerator (Sofia, 2020–2021)

As a minor foray, we would like to briefly discuss our experience in outlining the educational phase of "Beyond" a startup pre-acceleration programme based in Sofia, Bulgaria[7].

This experience represented a chance to expand the reflections developed in the Kick-Off Business Challenge to a substantially different context. As a first difference, the pre-accelerator involved a very diverse demographics — participants were around 150 students ranging from late high school to doctoral level — and a diversity of backgrounds, involving marketing, CS, business, and medicine.

Most importantly, however, since it was ran in the middle of the second wave of the COVID-19 pandemic, the pre-accelerator was conducted fully

[7] See https://beyondaccelerate.com/

online.

Our intervention focused on one of the earlier phases of the pre-acceleration programme, during which participants had the goal of acquiring the needed knowledge to proceed. In this phase, the most important taks participants had was to form teams and generate business ideas to proceed. For this purpose, the organisers of the pre-accelerator dedicated an intensive one-day online event, that we designed according to their requirements.

The change in setting made operations substantially different. As an example, mentoring tasks such as tracking a group's process are normally performed by quickly glancing on a team's table or overhearing team conversation. In an online setting, this is far more challenging: mentors need to intrusively enter student break-out rooms, potentially disrupting their flow.

We don't want to delve too much in describing the pedagogical design of this experience , which mirrors quite closely the diverge/converge model outlined in the Kick-Off section. Instead, we want to discuss the Digital Transformation process of I&E education taking an ANT-informed perspective on how the tools we use for online education shape the educational experience.

Teräs et al. called the rush to adopt EdTech during the 2020 pandemic a "seller's market' [219]. In what looks like another example of garbage can decision-making, the chaotic process that led organisations to adopt one EdTech solution over another was often not carried out by a deep and thorough analysis of these platforms' trade-offs, but can be seen as the fruit of temporal orders [137]. These choices had impacts in a number of etherogeneous dimensions: Watters argued that EdTech can be a way for surveillance technologies to enter the classroom [231]; Heher analysed various security flaws in a number of educational platforms recommended by the Austrian government, with potential impacts on the confidentiality of student information [102]; Ong showed how, in spite of their measurable advantage compared to in-presence meeting, even video conferencing carries a significant energy footprint [160].

There is, however, another relevant factor: when any software is brought in the classroom, it carries with it the intents of its designer — and parts of the context for which it was designed. A quite obvious example of this can be found in Zoom, which strictly mandates a social structure in each meeting: the Host has a degree of absolute platform-given power[8] that the physical classroom space does not give.

Table 2.5 compares some UX and social features of four highly popular video conferencing softwares. The table aims to show how the original intended use case and business model shapes in many ways the interactions that are possible within the video-conferencing space.

When teaching I&E, with all the aims and objectives that we have so far discussed, the transition to online education adds a further problematic dimension: EdTech tools that favour a mode of interaction may hinder the class' pedagogical methods and — as we have discussed how the method can embed a mindset and a content — its core message.

Our experience in the Beyond Pre-Accelerator is a brilliant tale of DT of I&E education. In spite of the initiative's success and the good level achieved by the students, the organising team had to spend a significant effort in wrangling with the mandated platform, and teaching methods had to be modified as a consequence of the chosen collaboration tools.

[8] Such as the ability to "mute" a participant without possibility of appeal.

	Zoom	**Google Meet**	**Microsoft Teams**	**Jitsi**
Original use case	Business meetings	General video-calls	Business meetings	General "community" video-calls
Revenue stream	Free limited plan, full product with paid tiered subscription	Free limited plan, paid subscription for enterprise features	Paid tiered subscription	FLOSS software, donations, option to pay company to host software
Who is the "meeting host"?	Pre-defined at meeting creation time	Pre-defined at meeting creation time	Pre-defined at meeting creation time	The first person joining the room, or pre-defined
Who can start a meeting?	Host only	Configurable	Configurable	Configurable
Who can end a meeting?	Host only (meeting can't continue without a host)	Host, or when all participants leave	Host, or when all participants leave	Meeting ends when all participants leave
Where is data kept or exchanged?	Zoom's premises (optional partially self-hosted plan)	Google's premises	Microsoft's premises	Wherever the server software is ran
Is a privacy or EULA required to participate in a meeting?	Yes	Yes	Yes	Not necessarily

Table 2.5: A comparison table between some UX/"social" features of videoconferencing software, showing some forms of embedded designer's intents.

2.3.4 e-Bridge Local Chapter (Aveiro, 2021)

As our last experience in I&E, we want to briefly discuss some work that we carried out at the University of Aveiro in the first half of 2021. In this context, we faced a very different challenge: how can we coordinate a university's portfolio of entrepreneurial activities to start building a cohesive I&E education offering?

The context we encountered at the University of Aveiro showcased a frequent issue that is found in the space of I&E education: a University might set up high-quality initiatives, and might have access to innovative learning spaces, but without a general vision and a strong coordination, it is nigh to impossible to achieve the desired impacts.

Our work in this space can be described as one of information architecture. Intervening in this context required a mapping and understanding of the existing projects and stakeholders at the University.

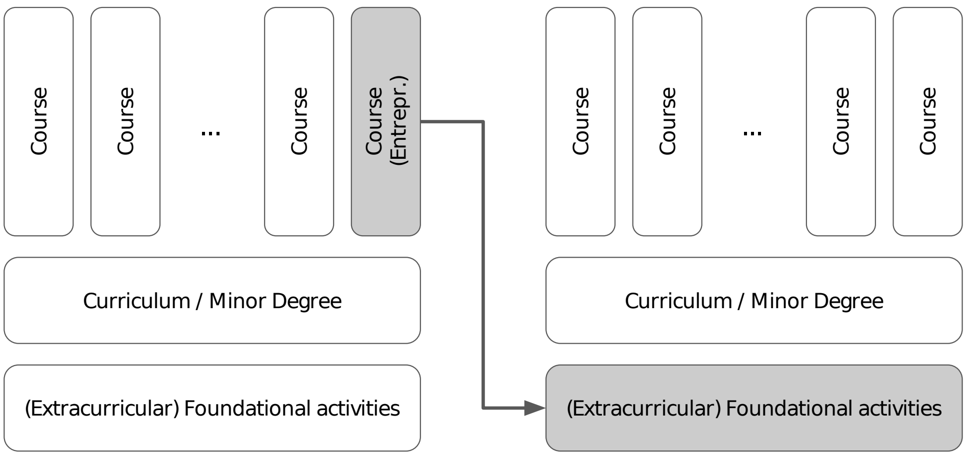

Figure 2.8: Moving the "entrepreneurial mindset" element from a vertical (course-) level to an foundational level.

Our general principle of "educating following practice" in this case, was brought to the meta-level: in the absence of a cohesive corpus of formal teaching activities that can be called I&E education, the (entrepreneurial) mindset can be embedded in the infrastructural activities (see Fig. 2.8).

Our proposed architecture for this context was to outline a set of activities that can serve as the backbone for further development of I&E education. The proposed activities are extra-curricular, in the sense that they are not required for the acquisition of a degree, nor do they award ECTS (at least initially). All of them, however, are designed to be of high added value for student at all levels — and potentially also for university staff and local stakeholders.

We say that these activities embed the entrepreneurial mindset at a meta-level because elements of entrepreneurship are not formally taught and assessed (as if mindset was a content), nor they are addressed horizontally across a number of courses (as in the case of the EIT Digital I&E minor). Instead, all of them are built from the loose "culture" that is normally encountered in entrepreneurship, that favours the direct sharing of experiences, and a community involvement.

We do not report in this context the full design of each activity, and we instead provide short descriptions (below), and a summary table (Table 2.6) that outlines the names of the activities and what actors are involved in them. These activities aim to build communities (of practice) upon which further work can be conducted. They are however also designed to minimise the amount of overhead required to run them, relying on existing coordination structures.

The proposed activities can be briefly summarised in the following way:

- Entrepreneurial Fortnights → Entrepreneurs whose startup is incubated in the University's Incubator share their lessons learned among each other and with the university's community.

- Teachers Community of Practice → A local Community of Practice on I&E education, initially coordinated by the rectorate, and then self-managed.

- Student Skill share → Students-led workshops aiming to share useful non-curricular entrepreneurial skills that students might have.
- Disciplinary Bridges → Short workshops to discuss how I&E can be linked to other scientific disciplines (changing every semester, with the eBridge's "sprints").
- Networks and Opportunities → A periodic review of available funding opportunities within networks the university is a member of, including both public and private calls.
- Grounding Activities → Basic activities such as orientation to the various actors within the University's entrepreneurial ecosystem.

This architecture represents a continuation of our reflections: if the goal is to teach I&E as a practice, that practice should be visible and tangible at all levels, including the institutional level. This work, in many ways, represented for us a chance to practice the principles outlined in Chapter 4 about achieving impact through orchestrating and organising inside an academic institution.

	Coord.	**Bachelor**	**Master**	**Doctoral**	**Faculty**	**Startups**
Entrepreneurial Fortnights	UA Incubator	A	A	A	S/A	L/A
Teachers' Community of Practice	UA Rectorate (then, self-managed)				L/A	
Students' Skill share	Design Factory	L/A	L/A	L/A	S	
Discipline Bridges	UA Rectorate (eBridge team)	A	A	A	L	
Networks and Opportunities	UA Coopera (University Cooperation Office)	A	A	A	S	A

Table 2.6: A table summarising the proposed activities, what stakeholders they involve, and in what capacity. L stands for "lead"; S for "support" (in organisation); A for "audience".

2.4 Instantiations

2.4.1 Technology Battles — First Conceptualisation

In this section, we present the first conceptualisation of the "Technology Battles" teaching methodology.

This is an adaptation with minor modifications of our previous work published as *'Enacting Divergent Learning Dynamics in Teamworking: the Case of Technology Battles'* (see publication list at 1.4).

Abstract

Demands over teaching methods have drastically evolved in the last decades. In particular, due to the increasing emphasis placed by the need to foster innovation, HEIs are called to frame learning environments accordingly, equipping students with skills and competences able to allow for some sort of innovative thinking. However, it is questionable if traditional educational contexts are able to cope with such a challenge. Indeed, it appears that their very design principles are much more conducive to what we here refer to as "convergent thinking". This form of thinking is focused more on confirming and consolidating existing knowledge rather than challenging and critically questioning it. Such a logic contrasts with both innovation related literature and practice, which emphasises the pivotal role played by the exploration of new knowledge as opposed to its incremental exploitation. Drawing on a theoretical analysis, this contribution identifies the key principles of a "convergent" classroom and, conversely, proposes conceptual counterparts in order to design a classroom able to enact divergent knowledge dynamics. If the principles for such a divergent model are those of equivocal ambiguity, counterfactuality and controlled conflict, convergent learning is instead based on their semantic opposites: unequivocality, factuality and conflict avoidance. An instantiation of these

design principles will provide, deductively, a possible methodology ("Technology Battles") inspired by debates in the English House of Commons. This methodology is contextualized in the experimental setting of the Innovation and Entrepreneurship minor of the EIT Digital Master School. Finally, some broader observations will be made, providing some considerations on how this analysis can contribute to a wider debate on the role of HEIs in contemporary knowledge societies.

1. Introduction: the need to enact divergent thinking in the classroom

Teaching methods have drastically evolved in the last decades. Education has taken under its hood the role of actively engaging students and trainers, and this has been especially seen in Higher Education (HE). In particular, due to the increasing speed in knowledge generation, learning goes beyond the acquisition of technical notions, and includes important elements of "meta knowledge" or "soft skills" such as social skills, creativity, critical thinking. In short, this unfolds in an increasing interplay between the capacity to master "content" (notions and technical knowledge), and "process" skills, addressing the need of "teaching how to learn" due to an accelerating knowledge obsolescence.

As suggested by many authors, and first and foremost by James March [136], knowledge creation can be described in terms of a twofold dynamics. According to the scholar of Herbert Simon, organizational knowledge creation occurs along a continuous trade-offing between two qualitatively different learning processes. On the one hand, by means of knowledge "exploitation", the current world view is incrementally consolidated throughout a retrospective justification of the present state of affairs. On the other hand, however, such a consolidation is complemented with knowledge "exploration" that, through a critical assessment of existing assumptions and interpretations, prospectively builds new, divergent knowledge options. Indeed, such an opportunity stems from a specific configuration of the world and the environment, which is said to be, more than uncertain, ambiguous. Ambiguity is referred to by many cognitive scholars as a situation in which multiple, alternative and even contradictory interpretations of the world can be enacted [233][65] [138][235].

As anticipated, this scientific framing has been evidenced by many authors according to different fields of inquiry. Indeed, exploitation/exploration represents just one of many such dualities that can be used to explain the structural and epistemological dynamics of an organizational environment. For example, in R&D environments, Boland and Tenkasi referred to the double-faced process of perspective making and perspective taking [30]; in the field of organizational psychology, Argyris and Schön produced the key distinction and analysis related to single and double loop learning [13], where the second loop is a form of learning that iterates on top of the first loop: a form of learning about learning (meta learning); in business literature, a constant reference has been made about the distinction between incremental and radical innovation [73] [49]; and finally, when analyzing the scientific process, the seminal work of Thomas Kuhn [121] refers to the dichotomy between normal and paradigmatic science, where the former is seen as happening within a paradigm, and the latter as a paradigm-shifting endeavour.

While this analysis has been mainly looking at a wide range of organizational settings, it is interesting to note that one of the main knowledge organizations of society has been left out from such perspective by educational researchers and pedagogists: the classroom. The classroom environment, when considered as a context where new knowledge is not just exploited but also explored, can indeed be framed in a similar way. Traditional educational contexts, hereby referred to as “convergent classrooms”, share the fundamental notion of approaching knowledge as an endeavour of experimental replication. The laboratory (here intended in its broader definition [124]) of convergent classrooms can take different forms, such as a frontal lecture or a more inductive, bottom-up class, and extends to learning activities which are designed both for single students and groups (team working).

Our inquiry, however, will be focused on the enactment of “divergent classrooms” in HE, whereby a divergent classroom is one requiring students to explore multiple, potentially contradictory, world views.

These two perspectives of the classroom help us in defining the broader concept of team working in HE through *divergent thinking* (or DCE - Divergent Case Enactment team working): an approach to learning that is mainly concerned with exploration, and which puts critical thinking (intended as the ability to reopen for debate the fundamental meta-knowledge underlying an existing knowledge body) at the forefront of the educational effort.

The very enactment of this divergent dynamic, however, is problematic. Indeed, addressing and living in ambiguity challenges and disrupts cognitive and social dynamics which construct our norms.These challenges can be grouped and simplified as the issue of the so-called “exiting out of the comfort zone”. For example, JS Brown [36] underlined how this dynamic challenges our social identities, and our consolidated organizational practices and routines [128] [13]. In the field of education, however, no pedagogical methodologies have been developed to enact these exploratory dynamics, and namely divergent thinking as a mean for learning in the classroom.

This contribution aims at presenting and discussing a possible pedagogical method to fulfill and enact this learning requirement, while contributing to bridge this gap. In particular, it will propose an educational methodology for teamworking in the HE context and attempt a first level generalization of the core principles underlying this methodology.

This contribution is structured as follows: section 2 will explore current approaches to team working in higher education, and how they are more strongly mapped to convergent learning; section 3 will give a first level grounding of the principles that can be put at the roots of a divergent approach to learning; section 4 will illustrate a first, concrete methodology that applies the provided theoretical framework; sections 5 and 6 will discuss the results of this application and draw conclusions and opportunities for further research and refinement of this concept.

2. State of art: Convergent classrooms and opportunities for exploration-driven education

The mainstream pedagogical approach to team working in HE, as well as in professional schools, has been focused, up to now, on the logic of "case studies" (CCS - Convergent Case Studies team working). This logic is not far from a laboratory's experimental approach and refers to different options that, due to space and scope constraints, will not be further discussed here such as analysing, discussing or presenting a given case. It can be argued for the sake of generalization that CCS typically proposes concrete instantiations of a relevant problematic situation and chiefly, in the current educational trend, business cases. Nowadays, CCS is widely implemented in top HE institutions and is said to be, by prominent business schools such as those of the MIT, Harvard and Cambridge, as the key pedagogical method for collaborative and problem-based learning [173]. CCS, however, appears to be deeply rooted on what has been defined previously a "convergent" approach to education, teaching and learning in the classroom.

In this case, the "convergent" dynamics stem from the analytical nature of CCS. In general, it can be observed that: a) the trainer provides to the students a "case" (defined, as explained above, as a concrete instance of a problem); b) students are asked to identify and reconstruct the facts and events that led to the case's success or failure, often in an inductive manner (i.e. teamworking) [174]; c) the evaluation of the learning performance, which might be either an assignment or a presentation, is based on an assessment of the ability to best justify the validity of the case (being it a "given" success or failure). This represents an exercise of "filling the blanks" (thus converging) between the case's beginning and the world as it currently stands.

This methodology is able to achieve many relevant and necessary steps of the learning process, but has an issue towards sparking innovative and critical thinking. Indeed, going back to J. March, CCS can also be seen as an exploitation-based pedagogy, where the space for enacting alternative and even conflicting scenarios in ambiguous contexts is limited. As a matter of fact, CCS generates new knowledge mainly by means of an incremental process of consolidation and verification of a given assertion ("the case"). This form of exploitation still ensures that learning is enacted but also has a tendency to allow for cognitive fallacies such as competence traps [129], superstitious learning [241], or path dependencies [108]. In a sense, these can be framed in what Taleb [214] called from a logical perspective the fallacies of induction, in which past experience is the main driver of understanding and interpretation, and knowledge is implicitly believed to be a necessary, and eventually all-comprising, progression.

The current absence of exploratory learning methodologies and divergent thinking in HE does not imply that these are theoretical concepts detached from practice. Indeed, in the last decades, the business environment especially has been applying divergent methods to foster a stronger attitude to radical/disruptive innovation [190] [190]. In the HE context, however, divergent thinking has at most been attempted in the form of "creativity" exercises or in the context of innovation-related courses. These display an underlying expectation that students will produce novel ideas (since these are the root of innovation), without providing, on the other hand, a sound and structured engagement method. As anticipated, divergent learning is not a spontaneous process and such an intuitive approach denies the need to address the social and cognitive factors that hamper innovation to take place, such as risk avoidance, social compliancy, peer recognition, and the need to confirm group identities [227] [236][162].

In short, it can be said that DCE experiments in HE share a common bottom line: unfettered exploration is not fostered in practice, either by context or by design.

In general it can be observed that, as summarized in Table 2.7, convergent thinking is explored both "within and outside" the class, while divergent thinking is more often addressed in the realm of practitioners under the wide methodological umbrella of organizational learning [191] [135]. As a result, today's classroom appears to be bound to develop along the lines of convergent thinking.

In class	Case Study Team Working	**NO EVIDENCE**
Out of class	Incremental Innovation	Radical Innovation
	Convergent dynamics	Divergent dynamics

Table 2.7: Where convergent and divergent learning have been explored.

3. Theoretical framework: design principles for a "divergent" classroom

In order to design a class setting able to foster divergent knowledge creation, it can be useful to challenge the key aspects that characterize convergence in classroom learning. For descriptive purposes, these can be elaborated as (i) unequivocality, (ii) factuality and (iii) conflict avoidance.

To further detail these three fundamentals, **unequivocality** refers to the belief that each knowledge body, be it a case description, a manual or a theory, has a univocal interpretation, constituting a given and unquestionable truth; hence, the inquiry work does not require falsification, but rather verification. **Factuality** relates to how every fact necessarily follows from the other in a logic of confirmation and incremental accretion. In this sense, it can be said that factuality creates a logic of supremacy of induction in the exploitation and verification of the given knowledge. Such a verification occurs through the collection and composition of existing facts. Finally, **conflict avoidance** implies that collective or team work is intended only in a cooperative sense, implicitly assuming that the development of conflictual interpretations and statements hampers the knowledge creation work. Hence, knowledge creation is assumed to be successful only if generated through collaboration and allowing for converging interests and views.

If these three qualities are proposed as characterizing of a convergent knowledge creation process, we hereby propose that their semantic inversion might define some key design principles to enact a knowledge divergent dynamic. These are (i) equivocal ambiguity, (ii) counterfactuality and (iii) controlled conflict.

In this framing, **equivocal ambiguity** can be seen as a cognitive situation or context in which multiple interpretations of the same facts are possible [135]. In such a setting the criteria of exclusivity for which if one view is admissible, then another is ruled out fades in the background. Alternative and contradictory views become possible and encouraged [65] moving the value judgement away from verification/falsification and towards plausibility. Examples of equivocally ambiguous situations can be found in any and all political debates: political parties construct arguments which support their world view, but opposing parties still can provide rebuttals and counterarguments, with neither party holding an objective "truth", and voters choosing, in the end, by means of persuasion.

Counterfactuality refers to a general cognitive attitude where reasoning is often developed by placing a counterfactual event into a logical inference. Namely, a counterfactual [89] is a fact that contradicts the current state of affairs, such as "In the sequence A>B>C, I observed that B happened after A, and thus C followed. But if X had happened instead of B, then Y would have followed, as a totally different outcome from C.". This cognitive attitude has also been observed and defined by Lewis as one generating alternative world scenarios [130], each of which represents a novel space for exploration. As an example of counterfactuality, we can look at scientific research: the act of altering the starting conditions of an experiment and the observation and recording of how the outcome changes represents a clear-cut example of an enacted counterfactual.

Finally, **controlled conflict** refers to a social dynamic in which different individual or collective actors engage with each other not to seek agreement, but to claim the supremacy of an interpretation over another. In our framework, conflict is controlled in the sense that it is expressed only dialectically and not by other means of power (e.g. violence, sabotage, etc.). Hence, controlled conflict is still a collective dynamic rooted in a form of social order, but in which knowledge creation is not achieved out of compromise, but rather of divergent confrontation. Controlled dialectical conflicts can be found very frequently in our media: moderated debates and panel interviews clearly show both the conflictual element and that of control.

Our research hypothesis is that these design principles can be applied in developing a learning environment able to foster and enact divergent learning, as shown in Fig 2.9.

In the following section we present our attempt to instantiate this theoretical framework in a concrete pedagogical method, that here we name Technology Battles.

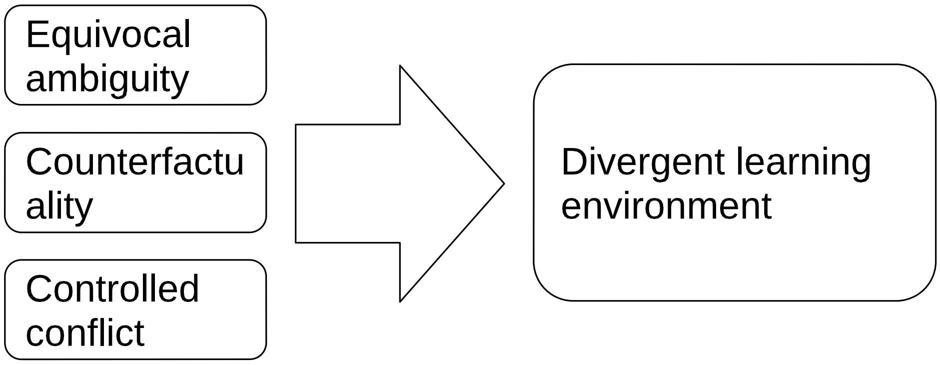

Figure 2.9: Our three proposed pillars for creating a divergent learning environment.

4. A first instantiation experiment: Technology Battles

An instantiation of the previous theoretical framework provides, deductively, a possible methodology which is contextualized in the experimental setting of its test case. In this contribution, such a test case refers to a number of courses belonging to the Innovation and Entrepreneurship (I&E) minor of the EIT Digital Master School[9]. A historical summary of methodological field tests can be found, at the end of the section, in Table 2.8. As anticipated, this methodology is here named "Technology Battles" for the reasons outlined below.

In order to generate a class setting able to allow for the three suggested design principles, we adopted a dominant metaphor, or said differently, a boundary object [204], which allow participants to intuitively stick to some groundfield rules (rigidity), while allowing for levels of interpretative flexibility (plasticity). Such a metaphor conveys in a simple fashion the key dialogical design principles and, at the same time, leaves room for further adaptation and interpretation. "Battles" are, at the bottom line, in-class debates, or enacted controlled conflicts, that refer to the English House of Commons as a life example. The House of Commons has been chosen as a reference by its virtue of representing well the principles of equivocal

[9]See `https://masterschool.eitdigital.eu/`

ambiguity, counterfactuality and controlled conflict. Here, the two main parties offer diametrically opposed views around a topic at stake for debate (**equivocal ambiguity**) with no middle ground for compromise. The topic can only be addressed by means of dialectics, thus representing a form of **controlled conflict**. Dialectics evolve around the constant and systematic propositions of counter-facts, namely, facts that counteract the statement of the opponents (**counterfactuality**). These features are also embedded in the very infrastructure of the confrontation, where representatives of the two parties face each other (conflict) and the center is occupied only by the rule keeper (control), the President of the House. For this reason we here refer to "Battles" while "Technology", as we will see, refers to the specific knowledge domain in which the learners are involved (ICT).

Shifting this metaphor to the classroom, students are divided by the trainers in paired groups of 4-8 people, and challenge the other group with the goal of convincing the audience (the rest of the class) that they represent the "correct" solution to a shared problematic situation. This situation, which constitutes the content of each battle (hereby "battleground") is drafted by the teaching team, with a focus on three educational dimensions:

1. A counterfactual-based scenario originated by a "what-if" question, where "what-ifs" are a generally accepted expression to refer to historical counterfactual scenarios. This allows students to detach from history and reality, promoting the exploration of the alternative worlds that stem from the counterfactual. Counterfactual can be placed in the past, such as "What if Steve Jobs had been cloned?", but also in the future: "What if humanity decided to move to Mars in 2020?".

2. A vertical/domain-specific priority to bind tightly each battle to the subject-matter of the students' studies. As said, in the cases presented

in this paper, the field of study of the students is ICT, thus qualifying the Battle as technological. As an example, the technical ground could be "privacy vs security" or a confrontation between QWERTY vs DVORAK keyboards.

3. An horizontal priority that gives each battle a broader interdisciplinary view, to go beyond a merely technical debate and open up to multidisciplinary content. In the cases presented in this paper, the horizontal priority is typically social or related to climate change. Such a choice is done in order to keep the problem and solution space as open as possible. As an example, a debate over migration or ageing population might open up to socio-economic observations, or an otherwise technical subject such as copyright could be approached from an ethical standpoint.

Once the battleground has been defined, the two groups are given an out-of-class shared meeting to discuss and negotiate the "rules of engagement". As "generals" agreeing on what "weapons" are allowed and what are forbidden, students are given an opportunity to redefine the battleground jointly, ruling out aspects that might lead the discussion away from the mainline content (i.e. focusing it too much on the counterfactual/fictional element) and altering the setting to be more favourable to their world view (e.g. agreeing not to discuss ethical implications). At the end of this meeting, each battle is ready to be carried out in class, and students are given time to prepare their and strategy. In this phase, they are assisted by appointed "critical minds", students either internal or external to the groups which provide defensive points to each team, informing them about their weak points, where they are attackable, and how to best defend. This allows teams to be always challenged to think critically.

Closely following the English House of Commons model, each group chooses one spokesperson who will deliver the opening statement for the group. She takes upon herself to represent the views of her team, going beyond her personal identity and beliefs. Once both groups have made their statements, time is given for cross-examination and questions from the audience. Towards the end of the timeslot, groups are asked to deliver their closing statement. As a conclusion, a jury (i.e. the electors/voters) proclaims the winner of the confrontation. Figures 2.10 and 2.11 briefly summarize a typical preparation flow, exemplified on a class slot of two hours.

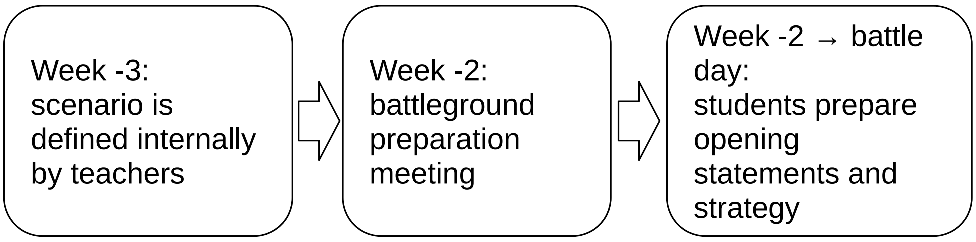

Figure 2.10: reparation before the battle. This assumes a regime of one battle/week.

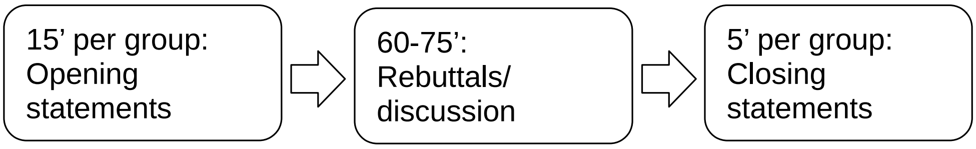

Figure 2.11: Class timings during the battle in a hypothetical time slot of 2 hours.

At the end of each battle, the “parties” are asked to jointly write a “battle report” in which they detail and conciliate the two views they were assigned. Such a conciliation is expected to be more than a mere summation of the two parts: in this sense, it should represent a step of synthesis rather than compromise. This aspect will be briefly addressed in the discussion and conclusions. The battle report, being the outcome of the two views at stake and following reconciliation, is where the divergent thought is concretized and takes a more defined shape. It is the step in which students are asked to make use of the lessons learned, interiorizing that equivocal ambiguity is a normal feature of the world context and that conflict, if controlled, is a knowledge generation moment. In this sense, it proves that only allowing for new scenarios, contradictions can be solved.

Course Name	**Academic Year**	**No. of students**	**Key Points**
"I&E Basics" - UniTN (EIT Digital Syllabus)	2013	100	First introduction of the "tech battles" concept.
"I&E Basics" - UniTN (EIT Digital Syllabus)	2015	120	At half course, introduction of counterfactual element and horizontal/vertical priorities.
EIT Digital Winter School - Trento	2015	15	First small-scale implementation, tighter time constraint (one week.)
EIT Digital ARISE event - Sofia	2016	20	One-day event, done outside the space of a proper classroom.
"I&E Basics" - UniTN (EIT Digital Syllabus)	2016	170	Complete run, with much higher numbers.
TEDD Course - Trento	2017	14	Small-scale implementation, with students from a different background.

Table 2.8: Summary of methodological field tests.

5. Discussion and observations: expected and unexpected results

Results of the application of this methodology have been promising, even if the methodology is still in an experimental stage. Due to the complex nature of the experimental setting and its social dynamics, results have been considered from a qualitative perspective. The main observations stem from the interplay of the three design principles that have been proposed.

The exploration of equivocal ambiguity led to the consideration of plausibility as a novel epistemological criteria, as opposed to the dichotomy of verification/falsification. While verification relies on the positivist narrative that knowledge discovery is a constant process of proving the truth value of an assertion, and falsification binds it to the possibility to falsify a scientific claim, the battle winner has been neither the group able to assert the truth of its interpretation, nor the one able to falsify the claims of the other. Given the time constraints and, more deeply, the intrinsic condition of ambiguity, successful interpretations were those that proved to be more convincing, persuasive, sound and well exposed also by means of different media. In a word, winning interpretations were those that appeared to be more **plausible**. This aligns well with the proposed theoretical framing, whereby ambiguity can be resolved only by means of intersubjective agreement and social construction [25]. In the class, every position could have been argued, but rather than seeing this as a problem, this fact has been embraced as a generator of the much-sought divergent knowledge. If, at the bottom line, an observation can be made, is that students did understand in practice that, aside from our social tendency to think of ourselves as truth/false driven cognitive entities, plausibility occurs in our very life experience in most circumstances, be them technical, political or social.

The design principle of controlled conflict has shown unexpected social behavioral patterns, and, if it could be said so, cognitive gains. Socially, the mandatory nature of the conflictual/confrontational setting led groups to situations in which internal contradictions were forced to emerge, convergent and compromising attitudes needed to be constantly compensated with critical counter arguments, and questioning gained a supremacy over answering. This last point is worth an observation: while traditional convergent learning poses an emphasis at questions as knowledge seeking moments (i.e. as drivers towards answers), in this setting questioning became a constructive practice able to exercise the capacity to disagree and respect disagreement as a key productive moment. Indeed, some of the positions that the students have expressed could only be generated in a setting in which each statement is cross-examined, questioned and criticized multiple times, since the very goal of each team was to defend/attack, rather than assert, a clearly subjective perspective. Furthermore, as a learning tool, it has made students able to address such a complex social dynamic in, somehow, a simplified fashion. Since the "party" to stand for was a given, a series of ethical/moral value judgement rooted in personal beliefs had to be put aside in order to "do the job". Said differently, given the task at stake, personal identities had to be challenged from the very first moment.

Finally, counterfactuals have created, possibly as a side effect, an ability to focus on learning as a double loop, rather than a single loop, commitment. We observed a systematic shift from a dialogue rooted in technical competence to one able to exploit important meta-skills, such as participation, confrontational attitude, ability to question and challenge implicit assumptions, and advocacy as a means to construct new social configurations. Hence, it has been observed that the key learning for the students was not much in an accretion of their technical knowledge, but rather in a deeper understanding of how the content specific to the instantiation connects with other topics, both within the discipline and in an interdisciplinary perspective. Such a "connectivity" was allowed by the creation of "meta-grounds" (creating the above-mentioned "horizontal priorities), which could more easily allow for switching from a domain knowledge to another. As an example, many battles have been debated on core ethical issues, and have given rise to many questions that revisited not only the scenario, but previous assumptions the students had with respect to the world and other social and economic issues. This ability to give rise to new questions and enact new hypothetical worlds in line with what has been described by Lewis [130].

Another point of observation relates to how the randomness in forming groups and assigning sides of the argument generates an exploration/exploitation dynamics internal to the groups. It has been observed that each group faces the implicit requirement of quickly and continuously switching between the two mindsets. On the one hand, an exploitation-driven reflection is carried out in order to justify the position each student has been (randomly) given, especially since the single members of the group might strongly disagree with their assigned position. On the other hand though, with the help of the "critical minds", the students need to examine how their arguments look like from the perspective of their opponents, going back to exploration. In this sense, we observe that the exploration/exploitation dynamic occurs at least on a bidimensional basis; along the class battle confrontational chronology, but also along the process of intra-group consensus building.

Having said that, the main practical challenge in successfully deploying this methodology appears to be in building a relationship of trust between students and teachers in applying such an unconventional methodology. The lack of familiarity from the side of the students caused courses to be subjected to "slow starts", since students felt a degree of disorientation with respect to how they were supposed engage in the class. This appears to be in line with the theoretical observation on the higher contextual difficulty of divergent thought, in this case given especially by risk avoidance and group identity.

Other salient variables that can affect the success of the methodology appear to be class size, length of the course, and time given to students to prepare for battles. In this sense, once more, some key tradeoffs must be undertaken. For example, we have observed that the time which is given to students to prepare their case should be carefully balanced to be long enough to give time to elaborate a more complex thought, but not so much that students can start iterating and approaching their own argument in an exploitative mindset.

6. Conclusions: From the class to the role of HEIs in contemporary society and back

In this paper, we have defined what we call convergent and divergent thinking. We have shown how divergent thinking has been applied to many knowledge generating contexts, but the classroom has been left behind. To bridge this gap, we proposed three design principles that could be adopted with the goal of facilitating this new unexplored applicative ground. A concrete instantiation, application and implementation in the context of an EU wide network of HEIs has been presented, along with reflections on the experiments which have been carried out with respect to the three methodological principles and other class dynamics.

The theoretical grounding of this contribution proposes, however, some considerations that, we believe, go much beyond the actual design of a classroom to allow for divergent thinking.

Why not consider a university classroom as one of the key knowledge fabrics of contemporary societies. This statement holds on some substantial premises as well as consequences. As a ground premise, HEIs are widely and unanimously claimed to play a pivotal role in boosting sustainable innovation allowing, as their core mission, for the systematic creation and transfer of new knowledge. Taking the EU as an exemplary playground, it has placed a number of instruments including the EIT, as fundamental in the making of the so-called Knowledge Society [57].

On the other hand, these very statements are always followed by a strong critical consideration and consequence: if HEIs are to play such a role, it needs to be deeply reformed [58]. What these reforms are about can be discussed at length, but this is not the place to do so. However, a very straightforward and somehow naïve consideration can be made. If universities are to deliver innovation, they need to be innovative; and in order to be innovative, they need to embrace and allow for innovation in their very vital functions, from governance to management and, undoubtedly, to education: the very reason why they were invented and still resiliently exist. Indeed, these modern monasteries took on board the mission to agnostically pass knowledge from generation to generation, culture to culture, across boundaries and throughout social turmoils.

Although this line of reasoning might sound very complex, our good news is that both the premise and consequence that we wish to propose are rather simple, if not again naïve. If a) the contemporary knowledge endeavour is much more about innovation rather than conservation; b) innovation is also and predominantly about divergent thinking; c) HEIs are called to become key innovation engines and d) classrooms are the core knowledge fabric of HEIs, we infer the following: in order to reform universities from within their inner circuits, classes should be also reformed in the same spirit, allowing for exploration and divergent thinking. This step is vital if they are to play their part in matching the paramount expectations placed onto this important social enterprise.

Going back to our contribution, we definitely do not have any pretence to fulfill such a tremendous task. On the other hand, we wish that our preliminary work, which looks like more like a question mark than a solution, could contribute to some divergent thinking for education policy makers, academics and pedagogists in reflecting on how the so called "classroom" can match the expectations of a socio-economic environment which is loudly calling for that.

To put in the terms of Ashby's law of requisite variety: "The greater the variety within a system, the greater its ability to reduce variety in its environment through regulation.". Said differently, in order to cope with the variety of contemporary environments, classrooms should embrace at least a similar level of internal variety. With the Battles we attempted to put some variety in that class. Indeed, sometimes the experience has been messy, but it has proven to be at least enjoyable for both trainers and students. We hope that future research and practice will propose and test alternative and even contradicting designs and methods to foster this variety. In a sense, if we are to embrace equivocal ambiguity, we look forward to alternative interpretations willing to engage in a battle with our contribution... of course, to be fought within the regulated conflict battlefields of an academic conference or journal.

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2.4.2 Technology Battles — Deeper reflections and impacts

In this section, we present a refinement of the "Technology Battles" methodology, emphasising how appropriately designed teaching methods can have a key role to spark student interest in subjects where they could otherwise show low engagement.

This is an adaptation with minor modifications of our previous work published as *'Prove Me Wrong! How Debating Becomes the Secret Weapon to Teach ICT Students Innovation and Entrepreneurship'* (see publication list at 1.4).

Abstract

Non-technical skills are now more relevant than ever for students in ICT. Many ICT degree curricula, however, still do not include non-technical education. Furthermore, even when non-technical courses are included, they are extremely compressed in time, and students have a low interest for these subjects. Teachers, as a consequence, face the aggravated challenge of carrying out their task in a context of generally low motivation. In this contribution, we present a novel debate-based teaching method called Technology Battles. We illustrate the theoretical, pedagogical and practical elements that led us to the design of Technology Battles, and discuss some preliminary results. These first results suggest that our teaching method was able to make the course's subject-matter more appealing to otherwise uninterested students, and bridge their initial negative bias. While some limitations remain in the ability to measure the obtained results objectively, we think debates might be a viable tool to introduce ICT students to the ambiguous nature of the socio-economic and ethical impacts of the technologies they work with.

Introduction

Think what they may, today's engineers are not merely puzzle-solvers. While some recent trends may make us think otherwise, our society has never seen so many scientists and engineers covering leadership positions.

From businesses to international institutions, organisations led by scientists and engineers have widespread influence on everyone's lives [202]. Indeed, the rapid technological advancement of the last decades shaped our reality not only technically, but also economically [9] and, most importantly, socially [211], [232].

At the same time, however, the education of technical professionals often focuses almost exclusively on technical knowledge [168], [140]. As an example, a 2011 study by Steiner and Belski [205], and later reprised by Belski in 2018 [24], shows that engineers' problem-solving creativity *decreases* over the course of their degrees.

While Universities are starting to follow up on the need to give non-technical education to engineers, many degree curricula in Computer Science (CS) and other ICT disciplines - with notable exceptions (e.g., [139]) - are often still focused almost exclusively on technical training. As a consequence, teachers of non-technical courses in ICT curricula face the responsibility of trying to fill the students' skills gap in very limited time frames.

In this paper, we present a teaching method for one such course in Innovation and Entrepreneurship (I&E) offered to Master's students in Computer Science and Information and Communication Engineering (henceforth, "ICT students"). This pedagogy aims at raising students' awareness and interest in socio-economical and ethical impacts of the technologies they will use and develop.

The generally low interest on the students' side for non-technical subjects [86] is the biggest obstacle we faced. In our case, this lack of interest arises from the top-down imposition of non-technical education (the course we present was made mandatory for the students), and manifests as a strong negative bias towards these subjects.

The course we present is, for a large majority of the audience, not only their first non-technical course, but also their only one. Therefore, our main challenge has been to create a format that can raise awareness and stimulate future interest in these topics in a compressed time frame. This new teaching method did not fully replace lectures, and has been introduced in the course as a "practical" component, similar to a laboratory.

We propose a debate-based teaching methodology, called Technology Battles, that puts students in an environment which is competitive in its presentation, but light-hearted and collaborative in its deeper design. The resulting learning space does not penalise mistakes and promotes forming and expressing personal views. This article expands a first conceptualisation of Battles presented by part of this research group in 2017 [33], showing how our design evolved, and sharpening the focus on Battles as a pedagogy for learning in ICT.

The use of debates to explore ethics and the impact of technology is not unprecedented. For example, Stanford University features a debates-based course on this topic, and another Stanford course taught ethics in CS by leveraging a number of different expertises in the teaching team[10] [176].More broadly, debating is a well-known tool used to create active learning environments [114], and has been used in a variety of settings, with different goals. From English Language Teaching [240], to childhood studies [37], to mechanical engineering [98], debates have been used to promote student interaction, foster active engagement with classroom content,

[10]Our own teaching team for these years has included entrepreneurs and academics from different backgrounds and at varying levels of seniority.

and develop critical thinking.

Debates bring subjectivity, ambiguity, and social dynamics into the classroom – all of which are in strong contrast with how ICT students see their discipline. We therefore use debates not to discuss facts, but to make students explore socio-economic themes in the ICT field with a non-technical mindset. In our course, this mainly means innovation, entrepreneurship, social impact of technology, and ICT ethics. We combine real-world elements with ideas taken from science fiction [141] to build plausible scenarios[11], creating a space for open-ended exploration. Language and frameworks are taken from popular literature in the I&E space, covering ideas such as growth mindset [209], design thinking [213], cognitive biases [113], systemic thinking [109], and antifragility [216]. Students are engaged in co-creating the debates, and teachers assume a role of mentors and moderators. This creates a learning space which has many of the ambiguous idiosyncrasies of the "outside" world, in the attempt to make the teaching as experiential and realistic as possible.

In the article, we will see how the proposed methodology was able to bridge a significant interest gap present in the class, and perform similarly to other non-lecture methods (e.g., labs) that students normally attend. We will start by providing some theoretical reflections that root our experimentation, and then proceed with a description of the methodology. We will then illustrate the evaluation framework and discuss the main results we were able to obtain, and conclude with some broader reflections and perspectives for future investigation.

[11] This technique is also used, for example, to explore the implications of policy proposals: `https://www.nesta.org.uk/project-updates/using-scenarios-reimagine-our-strategic-decisions/`

Theoretical Framework

Students in ICT, like many of their peers in science, tend to hold pure, objectivistic epistemological views [175]. I&E, by contrast, constructs its epistemology from the fields it borrows from: economics, business, and sociology; and holds more spurious, relativistic views.

The students' learning task, therefore, becomes harder: not only do they need to learn *what* are the main concepts of this new subject, they also need to learn *how* these concepts are created, and this is done through a completely different process than their main subject. ICT students approaching I&E, in other words, face a form of epistemological dissonance.

To reduce this dissonance, we grounded our (re)design of Technology Battles on three theoretical reflections:

1. Teaching methods should follow the epistemologies of the field they are teaching.
2. Methods that teach about a messy world should not shy away from messiness.
3. Focus on teaching mindsets and thought patterns rather than content.

The first reflection addresses the dynamics of scepticism that students express towards the new subject. The lecture format is the teaching method that students are most acquainted with [91]. It is - at least in the context where we are writing - the main way students learn about their subject, especially for grounding theory, with limited ability to deviate[12]. Students might hold a belief: what is taught in lectures represents a shard of an objective truth. Adopting the same method for I&E could pose an unexpected challenge: as students acquire more knowledge in the field and realise that the subject hardly gives anything in the way of objective

[12]Think, for instance, about blackboard explanations of mathematical proofs.

truths, the teacher's credibility would be undermined, compromising the teaching's effectiveness.

Technology Battles follow the epistemology of the discipline they are trying to teach. In I&E, the winner is often not the one that holds the objectively better technological solution, but the one that knows how to align the market to their interest[13] and navigate the world's complex socio-technical web.

A similar concept of "teaching using the field's knowledge-making technique" has been implemented by part of the authors in the context of a programming laboratory teaching method that follows the paradigm of "peer-to-peer instruction" common in tech start-ups [11].

The second reflection tackles the challenges posed by the tight time frame of the course, and tries to reduce the formality of the teaching setting. Creating a tidy environment for the sake of learning would surely make students feel more at ease, but could create extra challenges in the long-term. If students were to get the impression that I&E can be modelled and discussed in an orderly, tidy fashion, the transition from the classroom to the outside world would be traumatic.

Previous experiences that used debates for learning in technical subjects (e.g., see again [98]) often use debating to discuss factual matters. The social nature of debates is recognised, but the focus remains on acquiring a critical view of the course's subject-matter, rather than of its process: debates serve the course's purpose of finding answers through the emergence of questions.

In contrast, as we will discuss in detail later, Technology Battles try to create a setting of carefully-orchestrated chaos, relying on the teachers' expertise to create a debate that is at the same time focused, but also able

[13] See for example the numerous cases of competing technological innovation such as VHS and Betamax, the Concorde, Blu-Ray, MP3 standards...

to highlight and accept contradictions.

The third reflection addresses the constant state of flux the I&E space is subject to. The speed of knowledge obsolescence is ever-increasing [12]. At the same time, however, there is a considerable latency between the forming of an epistemological idea and when this idea is realised in the mainstream in the real world [161]. Given these two facts, it would not make sense to create a content-first teaching environment, since content would quickly get old, and examples would lose relevance.

Education often adopts the adage that compares giving fish with teaching how to fish. With this reflection, we opt to embrace the second part at the fullest: our goal becomes not to teach the use of a fishing rod, but to illustrate many fish-capturing techniques, so that students might in a second moment decide to try one - or develop their own.

In practice, from psychology to business, many disciplines have used roleplaying scenarios for a long time [37]. The three reflections that we have presented here draw inspiration in many ways from these experiences, and represent our attempt to bring these pedagogical tools to the field of I&E education for CS students.

Methodology Description

Technology Battles are a teaching method where two teams of 4-6 students debate opposed views on a common socio-technical theme during an in-class debate. Each Battle is divided into three phases: the *battle preparation*, the *debate* itself and the *battle report*. The *battle preparation* sets each Battle's scenario and rules. It involves the two teams, plus the teachers and two students acting as team coaches. The *debate* sees the two teams directly interacting with each other, while the teachers and coaches moderate the debate, with the rest of the class participating as an active audience. Finally, in the *battle report*, the two teams synthesise the knowledge acquired throughout the process in a joint document. This overall process is summarised in Figure 2.12.

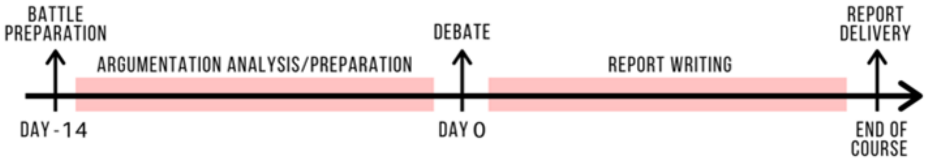

Figure 2.12: Summary of the Technology battles methodology timeline: from battle preparation (14 days before the in-class debate) to the battle report delivery (at the end of the course).

During the second or third lecture of the course, two hours are dedicated to a "meta" lecture that presents the methodology and motivations of Technology Battles to the students. The intent of this session is to ensure students are aligned with teachers on the procedure of the Battles, but also that they understand the motivations that led to the choice of this teaching method, and especially that they are aware of the Battles' pedagogical objectives.

Battle Preparation The *battle preparation* is a one-hour meeting done outside of class hours. Its goal is to define the boundaries of the debate, establishing what themes should be discussed and what should be set aside. Fig. 2.12 provides an overview of the Battle Preparation meeting, highlighting all the phases that compose it.

The first step of the Battle Preparation sees teachers briefly presenting a key socio-technical theme, and illustrating a fictional scenario that allows to "sandbox" the topic, reducing opinion biases[14]. Debate topics that are proposed range from entrepreneurial case studies (e.g., Uber vs Taxis), to

[14]The idea of using a fictional setting as a "buffer" to freely discuss emotionally loaded/politically controversial ideas is excellently explored, though in a different field, in a recent Game Developers Conference talk (`https://www.youtube.com/watch?v=Vf_bezxknxU`).

ethical trade-offs (e.g., Privacy vs Transparency), to futurology scenarios (e.g., competing models for technological utopias), to innovation dilemmas (e.g., Copyright and creators' rights). Suitable topics have a few key features: i) they are *active* debates (i.e., no clear-cut answer has already been societally accepted); ii) they allow for the definition of clearly opposed views; iii) strong arguments can be made for either position; iv) they clearly have an innovation, entrepreneurial or ethical dimension. Topics are typically proposed by the teaching team, though when students propose topics that are deemed relevant by the teachers, their suggestions are prioritised, in order to promote a model of co-ownership of the course.

Figure 2.13: Summary of the Battle Preparation phase for Technology Battles. Each Battle Preparation meeting goes through all these steps. The duration of the meeting is fixed (one hour), but each step does not have a fixed duration.

Once the topic and scenario have been presented, the participants (so the two teams, coaches and teachers) start a brainstorming session, extracting key concepts and words related to the topic of debate. Students freely propose keywords, which are all noted down on a blackboard, until no further proposals happen. Each keyword is then briefly discussed and voted upon with three possible outcomes: a topic might be included, explicitly banned, or removed as off-topic. Fig. 2.14 shows the blackboard notes resulting from a Battle Preparation session. Ideal topics for inclusion should have alternative views that can be argued, and exclude matters of sheer optimisation (where an "objective" answer can be found without space for debating) or excessively loaded with politics. This defines a common battle framework that focuses on interesting issues and minimises the chance of circling arguments.

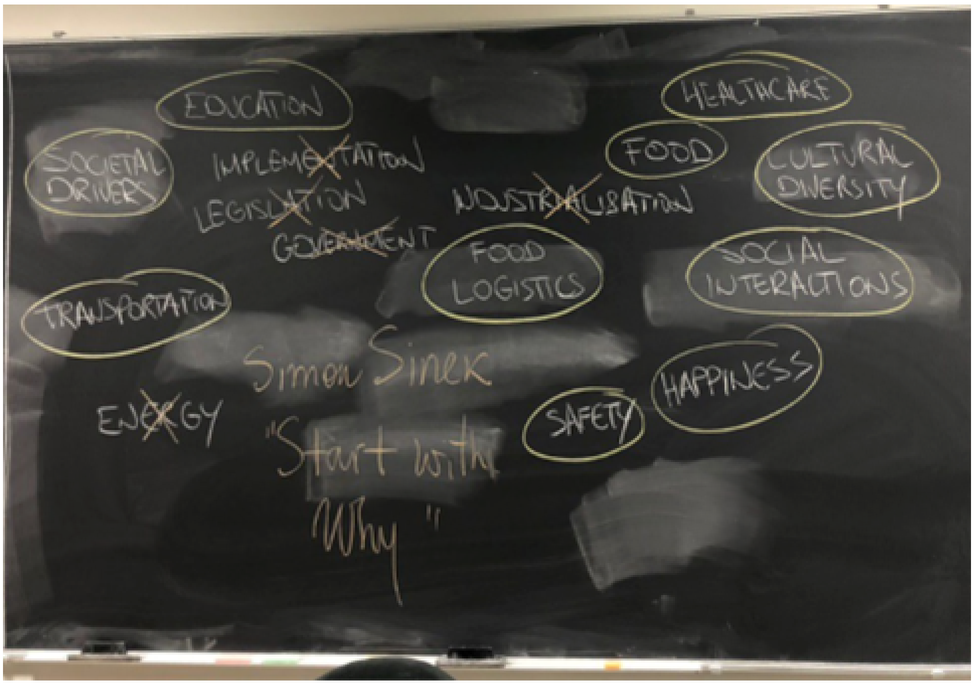

Figure 2.14: A blackboard with the notes of a Battle Preparation brainstorming phase. The topic of the Battle was "Smart Cities vs Smart Countrysides: models for future living". Circled keywords and topics have been included, crossed topics have been banned, and deleting smears can be seen where off-topic keywords have been removed.

Once keywords are filtered, participants jointly formulate a "case study question" with two possible answers[15], defining the teams' positions. As the last step, the teams choose which side of the debate to support (or are randomly assigned in case of conflict), and a coach is assigned to each team. The two teams then have two weeks to prepare their arguments for the debate, with the support of the coaches and, when needed, of the teachers.

[15] As an example, a Battle on privacy/transparency trade-offs will ask the class whether decisions should lean more towards privacy or towards transparency.

Debate The *debate* is a two-hours session conducted during class hours. It adopts the dialectic model typical of the British House of Commons [96], creating a debate which is open, sometimes chaotic, but governed. As in the House of Commons, the two teams are given space to express their positions, with one “spokesperson” talking at a time. The teachers, assisted by the coaches, moderate the discussion, ensure a balanced stage time, and enforce the boundaries defined in the battle preparation. The structure of each debate is summarized in Fig. 2.15.

The debate begins with two *opening statements*, one from each team. Teams are given 10’ each to present their opinions, data, facts, and stances: every presentation mode is allowed, from slideshows, to videos, to short acts. During the opening statement, teams not only present objective truths, but also attempt to sway the audience in their favour. No interruptions are allowed during statements, and the starting team is decided either by consensus or by the flip of a coin.

The bulk of the time (two slots of 40’ with a 10’ break between) is dedicated to a direct *debate*. Teams ask questions, illustrate their arguments and point out each other’s flaws, while the rest of the class takes a stance and tries to sway the debate in favour of one team or the other. Swaying the opinion is normally done by means of asking questions, but can also happen by direct intervention in support or against a given position. Much like in the British Parliament, sometimes the whole audience will react unorderly and noisily. Fig. 2.16 shows a class engaged in a Battle, where two of the teachers had to step in to moderate the debate.

As this phase is the core of the debate, proper moderation is crucial. To make the discussion understandable and successful, the teaching team and coaches have to pay attention to several factors: i) ensure that stage time and argument weights are fairly distributed between the two teams; ii) stimulate discussion around topics that connect to the course’s content;

iii) discard off-topic questions, as decided during the battle preparation; iv) maintain a varied *"tempo"* in the debate to promote attention; v) give as much space as possible to questions coming from the class; vi) when needed, repeat and rephrase answers given by students, providing a model of how to make a point sharply and clearly.

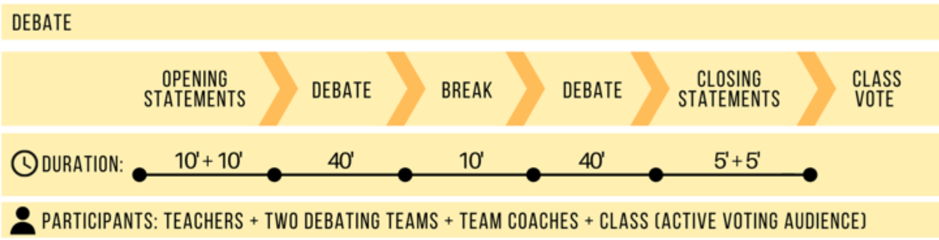

Figure 2.15: Summary of the Debate phase for Technology Battles. To ensure that teams have equal time under the spotlight, the debate is tightly structured, and each part has a fixed duration.

Many of these points arise from the students' variable experience in debating, especially around such subjective matters. Technological discussions can often be resolved by direct comparison, or by logical analysis of facts. Matters discussed in Technology Battles are instead – very much by choice – controversial. As we outlined in the introduction, the Battles environment is supposed to be competitive on the surface, but cooperative at a deeper level.

Naturally, students will try to use tactics that seem to be "cheap" ways to win, such as blocking the debate on a topic where they are at an advantage; hogging stage time; attempting to bring back banned topics that would favour their view, and similar strategies. While these "tricks" might be legitimate if the goal is just to win the debate, Battles are a *teaching method*, not a debating competition. Teachers therefore should create a more "balanced" debate where both teams' positions are always heard, even at the cost of forcefully shrinking a team's dialectical advantage at a given moment.

Towards the end of the two-hours class slot, teams are given 5' each for their *closing statement*, in which they summarise their position. At this point, each team attempts to once again establish why theirs is the "superior" position, and why the attempts at challenging their views were not successful. As the final step, each student in the class (except coaches and teams) votes for one of the two views, determining the winner of the debate.

Figure 2.16: A class engaged in a Technology Battle. In the picture, the two debating teams are standing at the left and right of the room. Two class teachers stepped up in the middle of the classroom and in front of the team on the right to moderate the debate.

Battle Report The *battle report* is a 10-12 pages document delivered at the end of the course that is written by the two teams jointly. The report includes a summary of the scenario, the theory background, the two teams' views, and the so-called *reconciliation* section. The structure of the report is summarised in Table 2.9.

The *reconciliation* section is at the core of the report. In this section, students are asked to provide a synthesis of what they learned from the debate, in the form of a new, shared narrative about the topic of the battle.

The reconciliation originates from three sources: the teams' original views, what emerged in the debate, and *ex-post* reflections. In other words, if during the battle each team tried to impose their own narrative as the answer to the debate question, now the teams are asked to cooperatively find a new answer that is more than the sum of parts.

The Battle Report thus becomes a deliverable that embeds the learning objectives of Technology Battles, and that goes back to the three theoretical reflections that we presented above. It follows the epistemological model typical of I&E (writing case studies, dialectically discussing matters of concerns); it provides a "messy" narration of the process that goes from the case study question, through the debate, and finally in the reconciliation; and it acknowledges that this is but one possible reconciliation, following the I&E mindset.

Section	**Description**	**Length**
Introduction	Introduction of battle's theme, general points related to the battle's topic.	1/2 page
Scenario	Presentation of the scenario negotiated during the battle preparation phase.	1 page
View 1	View and debated arguments from the perspective of the first team.	2 pages
View 2	View and debated arguments from the perspective of the second team.	2 pages
Reconciliation	A "Hegelian synthesis" of the debate. Teams cooperate to find a new view that is more than the sum of the parts. This is the main outcome of each battle, that emerges from the debate and ex-post reflection.	3 pages
Conclusions	Short conclusions to summarise the report and provide final thoughts.	1/2 page
References	References used for the report	∼2 pages

Table 2.9: Structure of the Battle Report

Results and Discussion

Experimental context The evaluation of the Technology Battles methodology was conducted through two surveys delivered at the end of the Academic Year 2018/2019 course and at the end of the AY 2019/2020 course.

The first is the nation-wide Student Evaluation of Teaching (SET) questionnaire. This is a standard SET questionnaire, as localised by the Italian National Agency for the Evaluation of Universities and Research Institutes (ANVUR) [4]. Students are required to fill the SET questionnaire on the University's Online Services platform when they sign up for an exam session, making this effectively mandatory. The questionnaire includes 12 questions on a 4-point Likert scale, plus an optional checkbox-based "suggestions" section and an optional, open-text "comments" section.

The second survey is an adapted version of a questionnaire developed by a professor at the University of Trento Department of Psychology. This questionnaire was already used to evaluate an active learning methodology, and has been used with minor adaptations in this study. Students were asked to fill this second questionnaire on the last session of the course via a Google Form on a voluntary basis. The survey contains 6 questions in a 5-point Likert scale, plus three open-text questions, all of which were optional.

Both questionnaires were anonymous, but required University authentication to reduce the possibility of multiple answers by the same person. In total, along the two years, we have gathered 273 unique responses to the SET questionnaires, of which 198 were considered to be attending students (and thus took part in the Battles), and 114 responses to the second questionnaire. The surveys partially overlap to provide a measure of cross-validation and reduce some biases that might be present in the data.

The main results we will discuss will be drawn from the Likert questions.

Both strengths and weaknesses of the Battles emerge from this data. However, to better understand the implications coming from the data, we first need to highlight some features of this study's context, both in terms of the course itself and of its students.

In our University's ICT Master's curricula, the class we are analysing is the only non-technical course, and passing the exam is mandatory for graduation in all curricula. This context creates two potentially adverse conditions that the course is inherently subject to. First, the course is large compared to other courses in the curriculum. Indeed, since it is attended by students from both CS and Engineering curricula, it is the largest course that students will attend during their Master's. This creates a first potential source of bias as large courses, compared to smaller classes, tend to have lower levels of student satisfaction and performance [14]. Second, as previously discussed, students in ICT are typically less interested in non-technical subjects - but even when they are, the procedure our university adopts to enrol in such courses is long and complex. This, in turn, creates an environment in which following non-technical courses is structurally discouraged. This represents a potential second source of bias, as it is highly unlikely that students will see non-technical education as a prominent aspect of their study careers.

To summarise: the course represents an outlier in the students' curriculum, as it is the only large course they will likely attend, it is likely their only non-technical course, and it is imposed on them as a mandatory subject.

Results and comments – Likert-scale questions These feelings reflect quite clearly in the questionnaires. Indeed, in the SET questionnaire, the question that gets the lowest score is asking for student interest in the subject. 40% of the students report they are either partially or fully not interested in the class's topics, against an average for our Computer Science Department of 20%. The balance between partially and fully uninterested students is also different: 50% of students in our course report having no interest at all, against a department average of 33%.

Strikingly, however, when students are asked in the SET questionnaire whether the teaching team stimulated their interest in the discipline, this bias seems to almost disappear. 18% of the students report a negative answer for our class, against a department average of 16%. The custom questionnaire agrees with this assessment, with 82% of the students saying the course engaged them.

We can contrast these two figures as representing measures of *a-priori* and *a-posteriori* interest and engagement. Under this light, these data points suggest that - while some critical points remain - we have been able to address the original negative bias.

We can attempt to trace some reasons as to how we were able to do this. One of the main points goes, indeed, in the direction of Battles. This intuition is rooted in another of the SET questions, where students are asked whether non-lecture teaching activities (in our case, battles) are useful in learning class concepts. 85% of respondents agree, in line with the department's average of 84%. This comparison gives rise to an interesting interpretation: Battles, while very different from other non-lecture teaching activities that ICT students are typically following (i.e., mostly labs and group projects), are perceived as equally effective.

Table 2.10 summarises these findings, also highlighting the *verbatim* formulation of the relevant Likert questions in the questionnaires, and mapping them to our interpretation.

Other measures in both questionnaires support the generally positive *a-posteriori* interest and engagement in the course. Students were asked to evaluate the appropriateness of teaching methods, the quality of the lectures, and the teaching team. Results from these evaluations also seem generally positive: 81% of the students consider the teaching methods to be appropriate; and the teaching team is evaluated as clear and professional by 82% of the students (83% in the SET questionnaire and 82% in our survey).

Original Question	**Interpretation**	**Value**	**Dept. Average**
Are you interested in the topics of the course?	*A-priori* interest	60%	80%
Did the teacher stimulate and motivate interest in the subject?	*A-posteriori* interest	82%	84%
Are additional teaching activities (e.g., tutoring, labs, etc), if they exist, useful to learn the subject?	Appreciation of Battles	85%	84%

Table 2.10: Summary of analysed Likert-scale Questions (from SET questionnaire).

Results and comments – Open questions Some more positive feedback can also be found in the open-ended questions. At a cursory glance, we have here another element confirming that battles were successful in stimulating students and generating interest. One feedback states *"[...] battles were fun and interesting, with different point [sic.] of view and insights for the different topics proposed"*, and another, in an otherwise extremely critical comment, says *"[...] battles actually present stimulating topics, and spark very interesting discussions"*. Most importantly, however, we can gather from here points of attention and criticism. Receiving offensive or unprofessional feedback in such a setting is a well-known problem [223]. Nonetheless, these answers can help both in making sense of the negative feedback, and in raising new points of interest.

A first such insight comes from the optional "suggestions" checkbox question. 84 students suggest improving the quality of the teaching material. The course always used sets of high-level, general slides plus a somewhat larger set of readings and keywords to explore further. The teachers' idea was that these materials should represent starting points for students to deepen their knowledge, and encourage further study of the course's subject-matter. As some of the written feedback suggests however, a number of students still felt the need for more traditional, easier to digest material. A student says: *"I think the methodology it's okey [sic.], but maybe it's necessary to have more write [sic.] material about the lessons"*, and another suggests to *"[...]keep [the] same format but add information on the slides"*. Interestingly, the proportion of students having this issue is somewhat similar to the one of students that were fully dissatisfied with the course (51 students). While the anonymity of the surveys makes it so that we cannot cross-reference the data between our surveys and SET questionnaires, it is clear that a fair amount of students would prefer more traditional teaching material. This criticism shows a low-hanging point of improvement for the course as a whole. Indeed, better formal learning material to accompany Battles, papers, and more general opinion/discussion readings would help to broaden the audience of students that are able to positively engage with the course's content.

Another frequent point of criticism refers to dealing with big groups (e.g., writing the Battle Report with other students and organizing meetings) and being part of a team in which that does not match students' expectations of teamwork. These comments put into question the current method we use to address issues such as free-riding [23] in writing the Battle report, and suggest we might need to redesign some parts of the methodology. On this topic, a student comments: *"I liked the idea of the battle, and i enjoyed both preparing to mine and partecipating [sic.] to others' but I really hated to have to work with 11 other people to produce the report. Seriously, some of the people i worked with had no interest at all*

[...]" and another states *"it's impossible to make workload equal for all, which creates issues of free-riding, as we all witnessed"*. On the other hand, however, we believe the issues students face in the current setup are very realistic and representative of the "outside world". If properly addressed, this could represent a growth opportunity that students may not face in other, more "sandboxed", classes.

As a parallel experiment, we also deployed Technology Battles as a one-shot experience in a class with the same educational background at the University of Nice, France. While the class was much too small to perform any significant data analysis (18 students responding to questionnaires in two years), we have observed similar trends and criticisms.

In summary, we think the surveys suggest that Battles are able to increase ICT students' engagement towards non-technical subjects. Most importantly, surveys also suggest that Battles can represent a good way to turn an a-priori lack of interest topic into a positive and enjoyable experience.

Conclusions

ICT students are prone to holding objectivist worldviews. By these views, innovation, entrepreneurship, business, ethics, and the other topics of our courses are often considered less interesting and less serious. Students most likely adopt these views in good faith, in a genuine attempt to give value to the technical skill set they are developing, and construct a strong professional identity.

As workplace demands on ICT professionals broaden beyond technical matters, Higher Education needs to ensure graduates are well-equipped to the challenges they will face. Beyond skills training, we argue that this requires a change in mindset. As technology becomes more pervasive and more people take up technical skill sets, excellence becomes more and more about the ability to navigate non-technical challenges proficiently.

Many students still express disinterest in these subjects, but we think the root cause is that most of them never had the chance to explore these topics in a context, which is at the same time formal (i.e., with a system of rules and access to trained experts) and safe (i.e., where consequences for mistakes are not dire).

Our work attempted to recreate such a context, and showed one way to do this: the dramatization of plausible debates rising from real socio-technical issues in the form of Technology Battles. This approach seems to work decently - if nothing else - to bridge the interest gap that students show between technical and non-technical disciplines, as well as reach comparable interest for Innovation and Entrepreneurship as they have for technical subjects.

Experiencing and participating in these debates seems to have helped the students in considering these issues as more "real" - while the class context created a safety buffer that kept discussion controlled. Indeed, at the end of the course, many of the students' deliverables and answers to the surveys show good awareness about socio-economic challenges and a first, even if naive, shift away from an "objectivist" world view.

While our first results are encouraging, some key limitations remain. First of all, the work we report on is only a single course done in the past two academic years, and we do not know if the results we have observed will last in the long term. The main limitation of this study, however, refers to measuring our methods' effectiveness. The complexity of our intervention makes it challenging to establish strong causation links between the course's design and the students' learnings and attitudes. Tackling this challenge is not easy, but future editions of this study should improve the data collection strategy to both be more thorough and more diverse in collected data. As an example, the course could integrate pre-surveys to track the evolution of the students' interest. Finally, we feel that it would be relevant to replicate this study in another context and with another teaching team. Involved teachers have been using Battles for a number of years, meaning that data might show a bias of teacher over-specialisation.

A possible direct comparison might already be drawn, as the course has been taught in two partitions (called "Innovation and Entrepreneurship Basics" and "Innovation and Business in ICT"). While these partitions do not present differences for the purpose of the present article, some differences in non-Battles teaching methods are indeed present. An analysis of the impact generated by these differences will be the focus of future work.

As a last reflection, we wish to discuss the research methodology that has been used to provide the backing data for this article. The present work has been conducted using mixed methods, primarily gathering data through questionnaires. While we feel that this mode of inquiry has been adequate to gather some first insights and start a data-informed reflection on the Battles methodology, we wish to pursue future work by going further in the direction of qualitative research. While we backed the design of the Battles method with several theoretical reflections, we feel that there is opportunity to further investigate how well Battles work as an epistemological model, and iterate our design based on such findings.

In these troubled times, we cannot help but ask ourselves how the work we are reporting here could change in the future. So far, online debates have not been a prime example of constructiveness. Nonetheless, our educational mission continues. Now more than ever, our community has the great opportunity to find ways to preserve and nurture the human ability to use disagreement and debate as a tool for growth.

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2.4.3 How DT complexifies the classroom space: the "Blended Learning Triangle"

In this section, we present a first analysis of the effects of the DT of education through the conceptualisation of a "Blended Learning Triangle" that explains the problematic relationships that arise from the interactions between students, lecturers, and producers of content used in blended classes.

This is an adaptation with minor modifications of our previous work published as *'Developing Engagement Strategies in the Blended Learning Triangle: the Case of I&E Education in the EIT Digital'* (see publication list at 1.4).

Abstract

Digitalised education is already a consolidated practice in Higher Education. Budget constraints and the need to target larger students cohorts show the benefit of leveraging educational content without increasing delivery costs. However, if on the one hand this "economy of scale" based rationale is the main foundation of the digitalised education narrative, on the other, such a view clashes with the need to address a series of novel social dynamics which are enacted by technological mediation.

This claim is rooted in a change of focus from just economies of scale to that of scope. When knowledge sources are diverse, fast-changing and interconnected, Blended Learning (BL) offers an opportunity to provide learners with a wide mix of contents which can be hardly owned by a single knowledge provider. However, in BL, the online part tends to drive its main value proposition, which turns out to be based on an efficiency-based view. On the other hand, positioning ICT as a means to produce complex educational content delivered to students interactively by trainers, transforms the traditional learner/trainer relationship into a three-dimensional learn-

ing environment made of content producers (CPs), class trainers (CTs) and learners (CLs), here referred to as the Blended Learning Triangle (BLT).

In this contribution we claim that these actors are traditionally seen as, somehow, disjoint. The question is whether such an interactional independence can be effective when dealing with complex knowledges instead of requiring a deeper engagement between them. This implies a problematization of the BLT, whereby these actors need to interact, cooperate and, plausibly, handle conflicts over demands of flexibility, adaptability and knowledge absorption capacity. This paper explores issues related to this problematization and, relying on experiences developed in the context of the EIT Digital, a pan-european network of HEIs, suggests possible recommendations to address these novel interactional demands.

1. INTRODUCTION: FROM "ECONOMIES OF SCALE" TO "ECONOMIES OF SCOPE" IN BLENDED LEARNING

ICT-mediated education, hereby referred to as digitalised education, is already a consolidated practice in education, and particularly in higher education (HE) [225][117] [67][38][22]. The decrease in Higher Education Institutions (HEIs) budget and the need to target larger students cohorts clearly show the benefit of leveraging educational content without increasing delivery costs. If, on the one hand, this "economy of scale" based rationale is the main foundation of the digitalised education narrative, on the other, such a view clashes with the need to address a series of novel social dynamics which are enacted by these forms of technological mediation [87][149].

Indeed, positioning ICT as a means to produce educational content delivered to students interactively by trainers, transforms the traditional learner/trainer relationship into a three-dimensional learning environment. Namely, these dimension are that of: (i) the producer that generates digital content, (ii) the trainer that interactively delivers it to learners, and (iii) the learner who has to engage with producers and trainers combining synchronous/asynchronous learning and online/onsite classes. As we claim, this statement is especially valid when dealing with complex and differentiated contents, which require flexibility, adaptability and effective knowledge absorption capacity [239][34].

The motivation for this claim is rooted in a change of focus from just educational economies of scale to that of economies of scope. Indeed, when considering a specific instantiation of digitalised education, namely Blended Learning (BL), the combination of online and onsite content delivery opens up the opportunity to consider other value dimensions in the design of new digitalised learning environments [88]. In particular, a key opportunity is represented by the possibility of going beyond the traditional efficiency-based economy and content replicability. Therefore, a key value of BL does not lie just in the sheer replication of standardized knowledge, but also in the opportunity to provide access to a differentiated pool of complex and fast-changing contents [149].

This opportunity addresses an underlying twofold need. On one hand, such a need is justified by the increasing speed, specialization and multidisciplinarity in contemporary knowledge production dynamics and learning requirements. On the other hand, in a learning context characterized by multiple complex knowledge sources which require a systematic process of cross-fertilization, BL offers a plausible opportunity to provide learners with the needed mix of options which can be hardly owned and managed by a single knowledge provider [22] [87]. Indeed, our experience has shown that high levels of student and instructor satisfaction can be achieved with BL approaches, ranging from online assignments, flipped classrooms, continuous evaluation and follow-ups. However such an opportunity becomes workable only when the so called onsite class is not just viewed as a sheer extra layer to the digital component, but rather as the enactment of a social context in which digitalised content can be adapted, updated and framed to be effectively absorbed by learners.

As a matter of fact, when dealing with complex knowledge products, trainers have to engage with a wider set of knowledge producers. These have to rely and trust a wider set of trainers, and learners need to trust producers while recognizing the legitimacy of the trainer. In particular, the key challenge is that of enabling the "active participation" of students/class learners (CLs) and engagement in a cooperative effort with both content producers (CPs) and class trainers (CTs) who run the class. In BL, these actors play in a context which is different from both purely online and face-to-face/onsite education models. In particular, there are two main differences: 1) the CP is not necessarily the CT who uses the content, and 2) the CLs interact not just with the CT but also, indirectly, with the CP.

Indeed, if such a shift from economies of scale to economies of scope is to be enacted, while standardization would simplify the interactional pattern through the provision of highly replicable content objects, complex learning paths require a constant interaction by the actors at stake in order to ensure flexibility, adaptability and effective knowledge absorption. When content is complex, actors do find themselves in a problematic cooperation context which requires a deeper understanding and development of sound engagement strategies. The ensemble of such a complex dynamic is named, in this contribution - the Blended Learning Triangle (BLT), and will be further explored in the following sections.

2. STATE-OF-ART: THE NEED TO PROBLEMATIZE THE BLENDED LEARNING TRIANGLE

In the last years there has been a growing evidence on the positive impacts of digitalisation on HE [17]. Indeed, much of the existing literature confirms that an institution can be more efficient in delivering knowledge thanks to digital technologies [87]. The most common rationale reported in literature on why HEIs decide to take advantage of it is to maintain course quality in response to increasing cohort sizes and limited budgets [193]. It is clear that this claim implies an efficiency-based / economies of scale argument: namely that, due to limited resources and increased educational demand, especially in the HE system, digitalised education can achieve greater volumes (number of students) at a lower unitary cost (cost of content delivery).

Such an approach implies a second order assumption; *de facto*, economies of scale are possible in the context of replicability, and replicability requires standardization. Hence, as it can be noted in mainstream cases, the main focus of digitalised education is on standardizable content that can be replicated generating economies of scale [149]. Not by chance, when focusing on BL, the online part of it tends to drive BL strategies towards the delivery of highly standardizable contents. In a sense, the strongest value proposition of digitalised education is extended to BL which becomes a key component of efficiency-based educational strategies of HEI.

However, it is clear that the onsite part of BL introduces a third player in the education process, making a distinction between the CT and the CP which were traditionally overlapping. While in both traditional and fully digitalised education both roles are played by one single actor (either in the class or in a digital environment), in BL the digital part is performed by a CP while the offline part is performed by a CT.

These three actors are however traditionally seen as disjoint, with each of them having its own issues at stake - i.e. CP needs to produce good content; CT needs to be a good presenter; CL needs to be highly motivated and engaged. If this interactional "independence" is workable in a logic of highly standardized content, where the CP produces replicable content, the CT delivers it (with already studied methods on how to do so [237][177][230], and the CL learns it [166], it is questionable if such a sequential logic can be applied in more complex learning situations. **The question becomes whether such an interactional independence can be effective when dealing with complex knowledge contents instead of requiring a deeper engagement between the three actors and thus a problematization of their relationship.**

In literature, such a case for BL to deliver more complex knowledge contents is clearly made referring to the need to have a closer look at its core value as rooted not just in economies of scale, but also and foremost in that of scope [34]. Indeed, it is hardly questionable that in the context of an environment characterized by the explosion of knowledge diversity and speed of change, the challenge in education is to provide learners with access to an increasingly diversified and dynamic "knowledges" pool. These generated economies out of diversity rather than volume, cannot be provided by a single knowledge source (e.g. the HEI), and are complex in nature. These circumstances imply a problematization of the learning triangle, whereby the three actors need to interact, cooperate and, plausibly, handle conflicts over demands of flexibility, adaptability and knowledge absorption capacity. Indeed, authors claiming about economies of scope do make the case that effectiveness is at least as much important as efficiency as both an issue and a value proposition.

This problematic issue is, however, not explored in existing literature. While effectiveness is mainly considered in terms of learning outcome evaluation [238][95][99], how such an outcome is achieved through the actuation of more complex engagement strategies between these actors is not given an adequate level of attention.

This is why the aim of this paper is to problematize the interaction between these actors in the context of an economies of

scope view of BL and, by looking at real world learning situations, explore the issue of which engagement strategies can be enacted to deliver an effective BL environment that addresses issues going beyond scalability. Traditional approaches in blended education have usually not been taking into account the need for diversity and there have been only few examples relying on complex network of knowledge production. This is the reason why, in the current paper, we explore the existing relationships between the actors and give guidelines on how to design effective engagement strategies to support such complex scenario.

3. SETTING AND METHOD: BLENDING INNOVATION & ENTREPRENEURSHIP EDUCATION IN THE EIT DIGITAL

The current study takes into consideration courses held in University of Trento, Italy, in the fall semester - end of 2016 and beginning of 2017. The courses were given to students enrolled in two different types of Computer Science Master's degree. Two lessons were part of the Innovation and Entrepreneurship (I&E) Basics course (a 1st year Master's level course) and four part of the I&E study course (a 2nd year Master's level course), both part of a minor in I&E[16], part of the double degree in computer science from EIT Digital[17]. Ten sessions were part of the professional Master's degree on Technologies for Active and Healthy Ageing[18] offered by University of Trento. Table 2.11 summarises all the settings in which our study has been conducted.

We took an approach based on "active learning" where students were required to watch a set of videos at home prior to the class, and then concepts were further discussed in class together with group exercises. As

[16] See `https:/masterschool.eitdigital.eu/programmes/minor`
[17] See `https://masterschool.eitdigital.eu`
[18] See `http://activeaging.disi.unitn.it/?lang=en_US&page_id=401`

a learning management system, all partner Universities of EIT Digital use Sakai, an open source learning environment used primarily for teaching purposes.

All the materials used for the study originate from the digital production of EIT Digital. Since 2014, six of the partner universities (KTH, Aalto, University of Trento, UPM, UPMC and TU Berlin) have produced more than 250 elements of online content ("nuggets") covering all EIT and EIT Digital Master School main learning objectives with respect to I&E education[19]. The focus has been on common I&E topics (such as Finance, Marketing, Pitching, Organizations, Human Resources, Value Chains, IPR, and so on) with every partner contributing to online contents based on their own specialization and competence. In average, the duration of a single video is around 10 minutes, and the videos come with assignments and slides to follow up the contents in class.

During this study mainly qualitative data was obtained. Insights were gained by interviewing different stakeholders in the process: CLs, CTs and CPs. Two CPs, four CTs, and dozens of CLs were interviewed; observation notes were taken during and after the classes. The results of the experience were presented in the bimonthly I&E group meetings of EIT Digital, where all partners presented their insights from the EIT Digital 'going blended' project, aimed to extend the use of EIT Digital online contents in the implementation of the I&E courses in each University.

The feedback from CP was that the content preparation was quite straightforward. The CP was involved to prepare a set of slides and the respective scripts or narrative to explain in a clear way the lesson to the audience. Once the content assignment had been planned the major difference from a frontal lesson is in the necessity to record the digital content in a specific setting (a studio in front of a cameraman) without the presence

[19]See `https://update.eitdigital.eu/portal`

of the classroom. Another difference was the attempt made from the CP to maintain the digital content concise, but still consistent, and make the lesson storytelling more engaging to students or addressee, as the digital mean leaves no control to the CP to check continuously the attention level in the classroom. The strategy of short digital modules helped the CL to maintain a good level of interest towards the educational content, without jeopardising their participation to the class but also to the overall learning path, and yet leave enough space (and freedom) to the CT to complement contents and allowed to integrate the learning methodology during the face-to-face phase.

The CTs participating in the study told us that if in traditional education, they felt as providers of knowledge, in the blended learning setting they were no longer bound to present instruction to the class and they had more time to dedicate on individual problems students had, observed students development and they had a role more of a coach then of a teacher. This also opened space for increased teacher-student interaction and CTs felt as they provided better individual coaching to each student individually.

With blended learning approach CLs felt that they have greater control over the learning process, and became active learners rather than passive listener. This change in role boosted their engagement and motivation, made them more responsible for the decisions, and made them responsible also over the blended learning process for the following generations, as they were asked to provide feedback on how to improve based on their experience.

In our setting we also had several attempts to study the interactions between the CPs, CLs and CTs. In three sessions, CPs came in class and took an active role, together with the CTs, in delivering the lesson. In this case the interaction between CPs and CTs was planned beforehand.

Forums and discussions were set in place on the platform so that the dialog between the CLs and CPs was continued online. Additionally, we asked the CLs at the end of the courses to provide feedback to the CPs on the contents and suggestions on how it can better fit their needs. The dialog between the CLs and CTs was observed consistently in all the blended sessions. In the following paragraph we discuss the further explore the relationship between the actors and we describe in detail the interactions we observed.

4. DISCUSSION

In the following section, we will explore the main issues that characterize the relationship between the three actors - the CP, CT and CL, in order to contribute to the development of effective and sustainable engagement strategies between them. The discussion is framed as follows: for each of the connections between these actors, we propose the key interactional issue, the problem from which it stems, related observations, a suggested recommendation for further work and improvement, as well as solutions which have been also piloted in the actual class setting.

CP to CT - Interactional issue: "ownership"

- **Observation**: Presenting content made by the CP without discussion and contribution of the CT delivers only very standardized, sterile and condensed knowledge without critical assessment. The CT should contribute with his own experience and provoke critical thinking on the students. The CT also needs to adapt the content to make it more relevant in the time and context the class is delivered;
- **Dilemma:** This is an issue which is revealed when the CP wants to make sure that the CT does not claim property on the digital content.

CT might adopt the "lazy" approach to simply reuse content made by the CP in an attempt to scale his/her own class more easily without recognizing that actually both may have equally good level of expertise in the field. There would be a stronger benefit in combining both actors' views and applying critical thinking to the content produced by the CP, which otherwise risks becoming a black box;

- **Piloted Solutions**:
  - Monthly plenary meetings ("I&E group") between CPs and CTs to qualify positions, points of view and competences of CPs and CTs and to establish direct communication and trust.
  - Creation of a network of HEIs and teaching contexts in which CPs and CTs exchange roles.
- **Recommendation:** Establishment of constant dialogue and interplay between the CP and the CT, including a space where they can reinforce and empower each other.

CT to CL - Interactional issue: "recognition" / "legitimacy"

- **Observation:** If the BL content provides the only perspective on the subject-matter of a course, either because the blended component is mandatory or featured too prominently, the CLs might challenge the CT's competence and not participate actively. Economies of scale are ensured, but economies of scope / effectiveness is lost.
- **Dilemma:** If CLs perceive the course as provided by somebody who is not the CT, an issue could emerge for which CLs assume that the CT is incompetent. This creates a dynamic in the classroom in which the CT is not taken seriously and illegitimized. In this sense, the baseline effectiveness of the class is compromised.

- **Piloted Solutions:**
  - Ask students to watch videos and find critical points at home and use it as a point to start class discussion.
  - The CT participates with his/her own position as well as complementing knowledge on the topic (content co-creation).
- **Recommendation:** Application of a co-creation approach to educational content by the CT. Goal is to ensure that CT's views are also clearly stated in class.

CL to CP - Interactional issue: "accessibility"

- **Observation:** CLs just watch the videos, go through the content and complete exercises without evaluating it and putting it into use and understanding its place in the context of information they received;
- **Dilemma:** the CLs might see the CP as an "ontology". They do not know who he/she is and / or assume that he/she is unreachable. This is a distorted view on the learning process, and leads the CLs to either assume that the content delivered by the CP is correct without space for critical thinking or that whatever doubt they might have will not be addressed. In this sense, learning becomes a matter of fact and is taken for granted.
- **Piloted Solutions:**
  - Have the CP interact directly with the class through forums, Q&A feedback or shared sessions. This breaks the virtual barrier which is put between CPs and CLs.
  - The CT should show that he/she is working together with the CP and should facilitate contact with CLs.

- **Recommendation:** Establishment of an ongoing dialogues between the CL and the CP facilitated in class by the CT.

The framing of this discussion is summarized in the following graphic representation (Fig. 2.17).

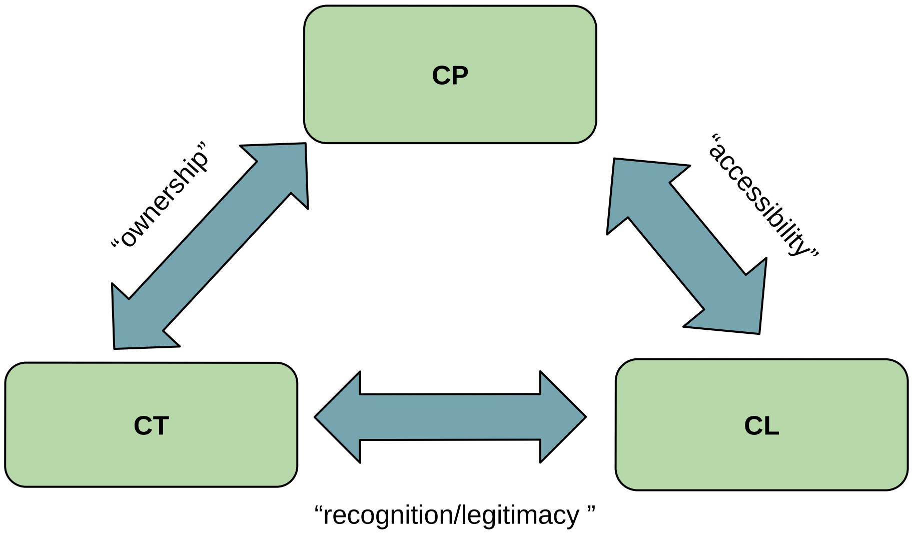

Figure 2.17: Blended Learning Triangle Dilemmas

Furthermore, another critical reflection related to the BLT emerges with respect to the recognition of the work done from the CP, which is somehow related to the content ownership and for which no solution has been piloted but here it is only proposed. CPs have been often involved only for a short time frame between the request of providing content on their specific expertise or area of interest and the conclusion of the recording phase. This may first and foremost disrupt their interest, but also hampers their effort in producing efficient and effective content to be used in BL. The education path designer, or the BLT responsible, who is typically the CT, should involve the CPs and agree on the whole course structure and modules from the early beginning. This would ensure a clear understanding from the CP of the entire learning path that the CL will follow, maximising the capability of CP to align his/her digital content to the overall content architecture. Moreover, the possibility to follow-up on what happens after the digital content has been provided to the CL could give a (positive) feedback to the CP, and so mitigate any potential issue on ownership and recognition which is a very relevant aspect as previously stated.

5. CONCLUSIONS, LIMITATIONS AND FUTURE RESEARCH: BL AND TRANSFORMATIVE DYNAMICS IN THE EDUCATION INDUSTRY

This paper aims to provide a further contribution to the exploration of the impact of BL in the evolution of HE. Analysing the concrete experience of a EU wide-network of HEI, EIT Digital, places our inquiry in the cross-domain between Computer Science and Innovation & Entrepreneurship. In the context of a society characterised by an increasing diversification, complexity and speed of change of knowledge domains, our analysis has been rooted within the research hypothesis that the core value proposition of BL shall not be confined solely in the search for educational economies of scale. Indeed, framing such a value in the logic of economies of scope provides BL the opportunity to be positioned as a key dimension in the transformative dynamics that are occurring in the wider educational industry which is notably also driven by digitalisation.

According to this framework, the clear cut split between the roles of CPs and CTs on a wide and systematic scale, poses a series of interactional challenges in what here we refer to as the Blended Learning Triangle. Addressing these challenges requires the identification of a whole new mix of engagement strategies which can redefine the shape and design of that knowledge fabric represented by "the classroom", a space that is now going beyond traditional organisational and geographical walls on the waves of both media and educational needs diversification. This contribution has been mainly conducted keeping the observation lenses on the main laboratory setting, once again the classroom. However, it opens up to reflections about the potential impact of BL at the macro-level, namely the educational industry. As noted by Clayton Christensen [51][50], disruptive innovations are increasingly taking hype when a new player alters the overall shape of traditional value chains, creating novel value streams also through the destruction of consolidated power centres[185]. In the educational industry, this power center is well known and well grounded in historical resilience: the academic professor. The professor is an actor who entangles both knowledge production and delivery in the same role. Our question would be: if these roles are split, also because of BL, what happens to this actor? It is also to be noted that the space in the educational arena seems to be widening for education managers, professionals and practitioners. Such a challenge represents both the limitation and opportunity of this contribution which is too small to provide a sound hypothesis but hopefully able to call for additional reflections.

Course Name	Course Description	No. of Sessions	Description of the set-up
I&E Basics	An introductory course where students are introduced to the basic concepts such as marketing, strategy, finance, HRM, IP management, economics, organisations.	2	160 active students part of the 1st year of the Master Programme in Computer Science. The two sessions were two independent lessons of the syllabus.
I&E Study	The I&E study course encourages students to incorporate their specific technical task line skills with the I&E concepts studied during the I&E minor. Students work on a case, and in the same time follow a set of 4 online modules delivered on I&E topics, helping them to deliver their final project.	4	13 active students part of the 2nd year of the Master Programme in Computer Science. Besides watching the videos they also completed peer-review assignments after each module.
Active ageing I&E minor	The purpose of the Advanced Course in Technologies for Active and Healthy Ageing is to create a number of professional figures with a wide variety of technical and social-health expertise. The course provides an I&E minor in which students follow sessions on fundamentals of project management, business modeling, innovation and entrepreneurship.	10	19 active students part of a professional Master's level specialization on Active Ageing. All 10 sessions were held in two weeks time - one session each day.

Table 2.11: Contexts where we experimented on the deployment of BL.

Chapter 3

The Machine

3.1 Introduction

"The Machine" refers to those parts of CS education that are technical in subject-matter. Our interventions, that mostly target graduate students, are usually not concerned with the fundamentals of CS technical education such as basic programming, but tend to focus on more advanced — and often high-level — subjects.

Under this light, the claim that CS education has grown disconnected from the machine might seem preposterous: after all, CS *is* about machines!

But if we hold our ANT view in mind, it becomes clear that machines are not inert objects. Machines embed the intents of their human designers, in an inextricably complex amalgamation, forming what Donna Haraway would call a *humus* [100]). Paraphrasing:

> Much like grabbing a handful of seemingly uninteresting soil to discover an immense variety of beings, even the most mundane contemporary computing artifact is a technological fractal — a genealogical maze.

The mutual nurturing relationship between humans and machines, however, is not proceeding at the same speed: the time span of a couple human generations corresponds to tens of machine generations. Most remarkably, human generations are growing *longer*[1], while machine generations grow *shorter*.

The digitalisation and Digital Transformation processes keep accelerating, and few things seem immune to these disruptions, not even CS itself. One of the few things that has so far proven particularly resilient to change (especially before the COVID pandemic) has been however the way CS is *taught*. Lecturing remains, in most of the education system[2], dominant. Computer Science tends to be positioned slightly better, as is the case for many STEM subjects [107], but the gap is still significant.

> As Digital Transformation, with all its constituent people and machines, reshapes all of our world, it falls upon us to consider whether it is time to pop the bubble where education has so far remained undisturbed.

In the General Introduction (1.1.2) we hinted at the many difficulties of defining a single type of educational intervention — and therefore research stream — to address the challenges we encounter. The same reasoning applies to technical education.

When designing interventions for graduate students, we can rely on the key assumption that students will have already acquired base technical knowledge, such as programming, in their undergraduate studies. Additionally, most students undertake advanced CS studies out of a wish to deepen their knowledge, and specialise in one subdomain of CS. Finally, CS students often engage in the self-driven pursuit of technical knowledge, for example to keep themselves updated [52]. Students will do this at varying levels, but this seems to be a common trait.

[1] At least in the Western world, see `https://ourworldindata.org/fertility-rate`

[2] See 1.1.1

These assumptions allow us to scope the general principle we presented in 1.2.3 whereby teaching methods should follow real world practices to define a general goal for interventions in Machine education.

> If students already pursue additional technical knowledge on their own, the common goal of our interventions will be to enable and facilitate the exchange of this knowledge.

Our work in this field will rely on pedagogical tools such as mentoring, peer-teaching and Learning by Teaching (LbT), with the ultimate goal of creating critical knowledge in and about the technical realm.

But if this is our goal, what are some of the "underrepresented challenges" of Machine education that this approach can solve? In this Chapter, we will mainly explore three: (1) Knowledge obsolescence; (2) developing soft skills relevant for technical professionals; and (3), as a particular instantiation of (2), developing the ability to successfully dialogue with professionals from other disciplines.

Our work will follow two Stories:

This chapter's Main Story will discuss technical education in a strict sense — most of our effort and results are in this field, and in this section we will also provide a Garbage Can description of the Problems, Solutions and Participants.

Then, we will explore a Side Story on so-called "fab education", namely that form of education that is encountered in makerspaces and similar facilities. This will be a precious chance to show how Innovation and Entrepreneurship can be connected with the technical domain from both a pedagogical and a mindset perspective. This Side Story is also particularly relevant in that this was the field where we developed many of the intuitions used in the rest of our research work.

3.2 Technical Education

3.2.1 Problems

We start our first Story with a simple observation:

> The speed of technological obsolescence is at an all-time high, and is increasing.

This fact has been observed not only anecdotally, but also in the literature — an excellent summary of which can be found in Arbesman [12]. One particularly enlightening representation of the technological obsolescence phenomenon can be found in Fig. 3.1 (or in research such as [27]). Though one can find flaws in any such popularity measurement methodology, it gives an effective representation of how language popularity fluctuates wildly in short time spans.

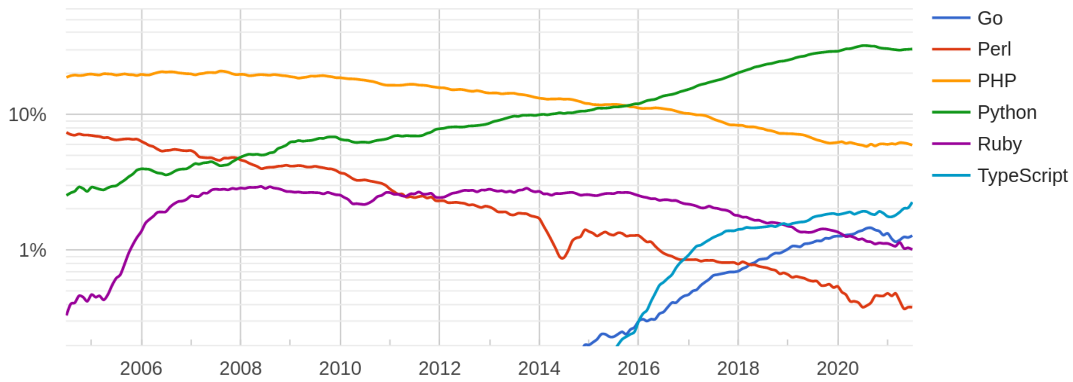

Figure 3.1: The popularity of some programming languages in the last years. Source: The PYPL Survey (`https://pypl.github.io/PYPL.html`).

In web development, this effect is even more dramatic. Popular industry surveys such as the Stack Overflow Developer Survey, track developer preferences for web framework usage. As an example, the Angular web development framework almost halved its popularity between 2017 and 2020.

It was the second most popular web development framework with a market share of 44.3% in 2017[3], second with 36.9% in 2018[4], third with 30.7% in 2019[5], and third with 25% in 2020[6].

Educationally, this creates a challenge: if Universities want to maintain their curriculum relevant, they would need to update their technical courses significantly and often, potentially every year. In practice, this — understandably! — does not happen often, as the effort would be nigh unbearable. There is, however, one more reason universities can afford not to update their offerings as frequently:

> While tools obsolesce and fall out of flavour quickly, more high-level concepts such as programming or computing paradigms are subject to much slower cycles.

Foundational elements of the Web such as HTTP or SSL are also subject to obsolescence, but the speed of this phenomenon is much slower. Because of this, a large majority of programming courses still employ older, "evergreen" languages [195], stating that their focus is on the foundations rather than the implementation.

At the same time, however, the jobs market has radically different demands: even authors of automated analyses of jobs posting such as [212] highlight how job offers frequently require candidates to have experience with specific languages, frameworks, or tools. Nonetheless, if Universities want to fulfill their mission of making students employable in the jobs market, they cannot ignore that this is a reality.

[3] `https://insights.stackoverflow.com/survey/2017#technology-_-frameworks-libraries-and-other-technologies`

[4] `https://insights.stackoverflow.com/survey/2018#technology-_-frameworks-libraries-and-tools`

[5] `https://insights.stackoverflow.com/survey/2019#technology-_-web-frameworks`

[6] `https://insights.stackoverflow.com/survey/2020#technology-web-frameworks`

In the jobs market, experience with tools becomes a **value** through which applicants are measured and benchmarked when seeking opportunities. Our contribution to this debate, however, is in reconnecting this to its philosophical origin. There is indeed a branch of philosophy that is concerned with discussing and comparing values, namely ethics, meaning that:

> If experience with a tool is a value, and this experience is not easily transferable, the choice of a tool over another can add - or subtract! - value from students' experience and career prospects. In other words, the choice of programming languages and tools is, in the design of a CS curriculum, an **ethical** choice.

Achieving high student employability is a key (ethical) concern for Universities in the design of Computer Science curricula.The low rate at which courses are refreshed in terms of tools in spite of the increasing speed of technology obsolescence show that Universities need to improve. Solving this challenge, however, cannot come at the cost of course quality and technical expertise.

Students in CS still hold their technical expertise has the highest value they get out of the education process. As their expertise is measured in terms of what they are able to do with the tools they are trained in, the choice of tools in CS curricula is again cemented as a value judgement. But are students well-equipped to create such value judgement? What other skills should be part of the technical tookit of a CS professional, to add to their value? Can graduates leverage these other values when seeking job opportunities, and how do they compare them to the value of technical expertise?

We argue here that these questions are not asked enough in the current context of technical education, and thus represent one of the "underrepresented challenges" that this thesis seeks to address.

A book edited by Ulrich Teichler, *Careers of University Graduates* [218], sheds more insight in this sense: graduates have different levels of awareness and different aims for their work life: so why does it happen that (p. 132) graduates still percieve that they have a surplus in "knowledge" skills?

We argue this is not due to a failure of the educational system in equipping students with technical skills. On the contrary, we can see this, once again, as a matter of values: an underdeveloped ethical compass hindered students in one of the first parts of their career development, namely the discovery process.

To summarise, the Research Questions (RQs) we propose to explore in this Story are:

1. How can we create technical education that is resilient to technological obsolescence?
2. What non-technical skills can technical education easily and effectively develop, and how can they be taught?
3. What can teachers and curriculum designers do to help students understand all their (competitive) assets?

3.2.2 Solutions

Our exploration of the solution space started from a few general questions:

> How does "ambiguity" manifest itself in technical education? What are the key assumptions and educational practices that need to be changed?

We will reconstruct the design of our intervention in the space of technical education tracing the RQs we discussed above. These questions are the expression of a need, which we used as the guide for our pedagogical design. Exploring RQs, we will

Resilience to Technological Obsolescence

To create courses that are more resilient to the technological obsolescence process, we first need to identify what elements of the educational experience are most subject to it, and what this obsolescence implies.

Different components of CS courses — and different sub-disciplines within CS — are involved in development cycles of varying speed. Obsolescence is a problem that involves all of human knowledge (see also [12]) and this happens, again, at varying speeds. To conduct our investigation in the first RQ, we turn to a sub-discipline that moves particularly fast: web development.

We will further discuss the idiosyncrasies of why web development was chosen as our field of analysis in 3.2.5. For now, it should suffice to say that web development is one of the fastest-evolving subjects in CS, with fast disruptions happening not only to its programming languages, but also to its more general paradigms.

So, what are possible concrete steps that we might take to make courses in this field more resilient to these disruptions? We argue that a first step in this direction is to create courses that are *language-agnostic* (or at least tools-agnostic). While a first naive solution might turn towards making courses more abstract, this is not enough, as it is commonly agreed that CS courses should give a significant space to hands-on experience.

One possible solution that we focused on starts from an empirical observation that many of us, as teachers, have probably seen:

> For any piece of content that a teacher discusses in the class, there often are students who are already (at least partially) familiar with it.

While the class as a whole can benefit from an "authoritative" exposition of the content, parts of it would surely be less engaged. When the explanation involves particularly recent technologies such as development frameworks or libraries, it might even happen that some students might be more familiar about them than the lecturers. This, in turn, testifies to the presence of *pockets of latent knowledge* in the classroom. One of the ways in which we can tackle content obsolescence is to leverage this latent knowledge. Indeed:

> As teachers, we can design an appropriate pedagogical intervention to put this latent knowledge at the class' service.

This might seem like a shift of responsibilities: content obsolescence becomes something that the *students* need to address rather than the lecturers! Far from this, the approach we have experimented is that of shifting the teachers in a role of mentors. As we have seen in 2.1, this requires a different skillset (and mindset) from the side of teachers. Most importantly, the close mentoring of students from the teachers' side requires a substantial extra time commitment.

The role of the teacher, then, can become that of helping students share the latent knowledge they possess. Different courses can and should adopt different strategies to perform this task: in our case, as many CS courses tend to be practical in nature, students can take the leadership in a laboratory/tutorial session. As students cannot be expected to have all the skills they need to deliver an effective lab session, the mentoring teachers need not only to ensure that the content is appropriate, but also that students can *teach* it appropriately.

This, in other words, is not a process of delegation, but one of co-creation. Teachers remain responsible for the successful achievement of their course's LOs, as well as the overall delivery of the educational experience. They can share, however, the responsibility of making this relevant to the students' *interests*, and their wish for market relevance, with the students themselves.

A particularly relevant implication of this model is that teaching material co-created with students can and should be given equal dignity to the one produced by teachers. Courses adopting this approach can, therefore, create an incremental legacy for future students. Material presented in the course takes a different connotation, with content taking a more "transient" character, rather than being seen as a static, permanent artifact.

Creating education that is resilient to technological obsolescence thus becomes a matter of creating an in-between space that sees, on the one side, the traditional centralised classroom model, with the lecturer as the sole holder of knowledge and, on the other, fully peer-to-peer knowledge creation[7].

Drawing an analogy, we can map the knowledge in the class as if it were a networked system: the lecturing classroom can be seen as a *centralised* network; the tutoring classroom as a decentralised setting; the Learning by Teaching (LbT) classroom, with its peer-to-peer knowledge-making, as a distributed network (see also Fig. 3.2)[8].

Skills Development in Technical Education

To find potential answers to the second RQ, we need to highlight that there is a strong interplay between two elements:

1. The skills we wish students should develop.
2. The pedagogical methods we propose to use.

[7]Dominant in knowledge work such as research or peer communities such as those making open source software

[8]Notice however that the network is meshed only on a *per-group* basis.

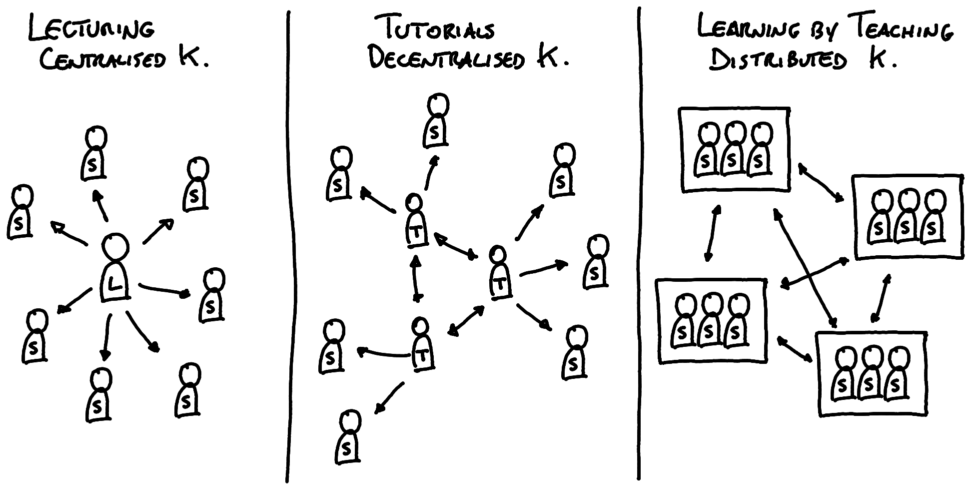

Figure 3.2: A visual comparison of lecturing, tutorials and Learning by Teaching as knowledge exchange and knowledge-making spaces. Arrows represent flows of knowledge. In the LbT part, flows internal to groups and the teacher/mentor are omitted for visual clarity.

In other words: the desired skills should inform what pedagogical methods a class adopts, and the pedagogical methods should be tailored to maximise their effectiveness in developing those skills.

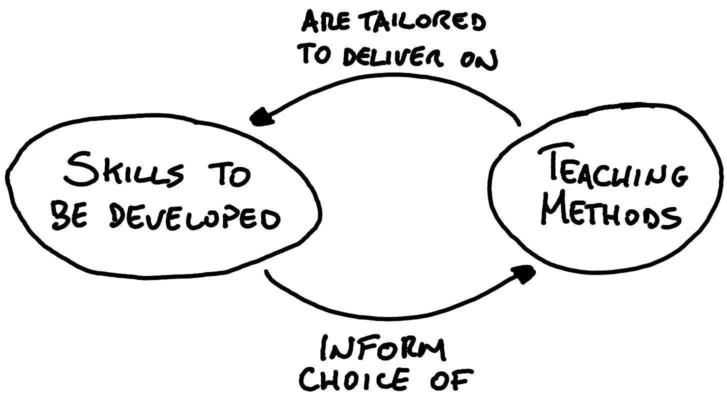

Figure 3.3: The link between skills and pedagogical methods.

Nowadays, a vast majority of jobs that CS graduates are taking are conducted in group settings [200]. The main skills that we want to develop in participants, therefore, are interpersonal in nature, and fall in the loose bracket of "group skills".

A few such skills are oriented to enhancing the students' ability to deliver high quality technical artifacts, but most are more process-oriented. We want to briefly discuss here a few of them:

- Peer teaching and knowledge sharing.
- Team management.
- Product planning and continuous delivery.
- Learning skills.

Perhaps most obviously, the methodologies we experimented for technical education aim to develop the students' ability to teach to each other. Most of the practical knowledge necessary to perform coding jobs is not found in textbooks, scientific articles, or other forms of highly-structured and static documentation. Instead, most coding knowledge is held in forums, wikis, mailing list threads, chat channels, or exchanged directly in various collaborative spaces.

Most CS curricula include a great amount of practical project work, but only few curricula have dedicated learning spaces to teach students how to collaborate effectively, with most courses still relying on lecturing and tutoring sessions. The industry, on the other hand, regularly adopts strategies such as pair programming to facilitate code reviews and knowledge sharing within teams. Though introducing these practices in university courses using the same structure as their "real world" counterparts is possible, it is not easy to set up. The methodologies we propose take some trade-offs, but closely mirror these practices.

The "Learning by Teaching" solution that we described above can be seen as a compromise between tutoring and pair programming (see Fig. 3.4) whereby the meshed architecture found in pair programming is reproduced on a per-group basis. Furthermore, our previous discussion (in Fig.

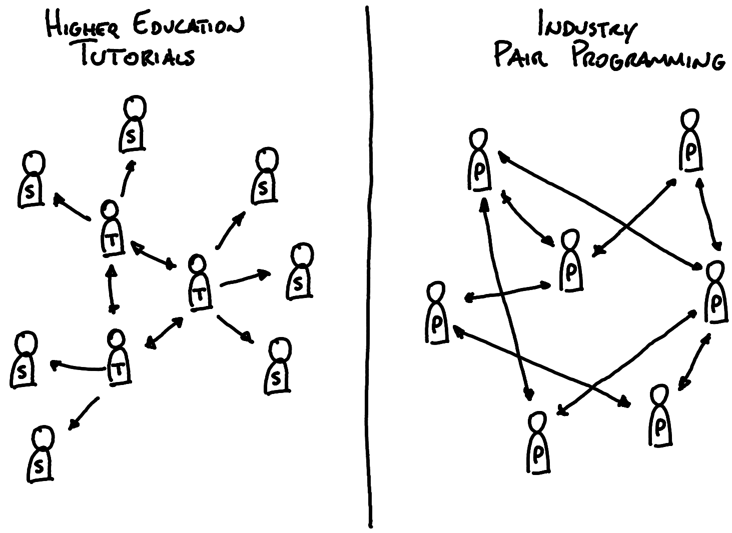

Figure 3.4: A comparison of knowledge flows in a tutoring classroom and in pair programming. Pair programming represents a fully meshed knowledge architecture, where pairs are created on the fly.

3.2) omitted one key role: that of the classroom teacher, who shifts their role here to that of a mentor.

We refer to "mentoring" in this setting as a general process where a more experienced figure (the mentor) facilitates the learning of a less experienced figure (the mentee) in a small-scale, if not individualised setting, that is often informal in nature [53].

This process enables the shaping and sharing of latent knowledge, as discussed in Section 3.2.2. Mentoring happens at at least two levels: first, the class teachers mentor students holding latent knowledge into how to effectively share it with their class community; second, those students take the mentor role themselves, and teach to their peers. In the case of a setting where *teams* of students share their knowledge, there might be an intermediate step of knowledge sharing, as experienced group members get their team-mates up to speed.

Internal team management and division of roles is another competence that is developed through this type of knowledge-sharing pedagogies. The choice of a properly-cadenced time frame for the execution of classroom activities should encourage students to internally divide their work so that all team members can contribute somewhat equally. Teachers should mentor students into taking different roles within the team (similar to what we have seen in 2.2.2), to make sure everyone has a chance to contribute.

Another skill that is developed in this setting is that of planning the development and delivery of a product so that workload is properly distributed in time, enabling a form of "continuous delivery" commonly found in agile processes. An appropriate design of the teaching setting should make sure that students can develop their contributions incrementally, and can access teachers' feedback often and iteratively.

By preparing a structure of checkpoints where students can present products that are as close as possible to being deliverable, students practice a form of agile development of their knowledge-sharing sessions, naturally falling into team roles and approaching each checkpoint as a "sprint".

Finally, we want to refer to learning skills. While each student will, during a course, have a chance to teach, they will spend most of their time learning from their peers. Even though they share a common background, peers will have radically different teaching styles. Each student therefore is exposed, in an extremely limited time frame, to a variety of contents and approaches. In turn, this means students are encouraged not to approach each concept as a vertical silo, but rather look at the bigger picture, and how each piece of knowledge fits into the space of the discipline they are learning.

Promoting student understanding of skills

The last RQ (and last need) that we want to explore is to make sure students can understand and self-assess their skills not only in terms of technical proficiency, but in a broader view.

The role-based team structure discussed in the section above (and in 2.2.2) makes it so that each student needs to contribute to the common goal with a different expertise: a student might take the role of the tools expert, one of the technical troubleshooter, one of the presenter.

As students naturally gravitate towards their preferred role, teachers need to make sure that their contribution is commensurate to the other team members'. Each student should further their expertise in their role, while the whole group should aim toward achieving the course's LOs. A suitably-designed pedagogical method will empower each role and each team, furthering the idea that "to teach is to learn twice".

Particular care should be put towards evaluation. One of our interventions, presented in Section 3.2.5, will exemplify what we mean by this (see in particular Fig 3.1). As students will be required to teach peers during their professional careers, it makes sense that this skill, while non-technical in nature, is included in their evaluation.

As a side-point to the above, a particularly relevant point is that of ensuring that students have some level of slack or scoring tolerance when they are evaluated for non-technical skills, as they might feel that it is unfair that they are evaluated for something which is not strictly technical in nature.

The integration of elements of ethics and non-technical subjects in CS curricula also aids students in building and consolidating their expertise in creating deeper value judgements about matters that are both technical and non-technical in nature. If students are to acquire a deeper comprehension of what their competitive assets will be once they enter the marketplace, they need to be trained in recognising and assigning value to skills. Many of these competences are nowadays developed in what we have called "I&E" courses, but it should be apparent by now how they are essential to technical profiles.

Finally, and as a key way to consolidate all of the above, we argue for the need to promote a deep and frequent contact with the industry. Students will, naturally, rarely have first-hand experience on what are the competences that are most sought in the workspace. Many companies keep their recruitment process opaque, and list soft skills only in general terms on job postings, but nonetheless most jobs *do* list soft skills requirement.

Contact with industry in technical courses can take many forms: the most obvious are probably guest lectures, the integration of industry experts as lecturers and frequent career fairs, but again, pedagogy can assist in deepening this interplay. Methodologies such as CBL have been successfully adopted in technical education (see for example [182]). We will discuss some ambitious plans for the wider deployment of CBL pedagogies in section 4.2.4, but a technical course that sources challenges from the industry might be an interesting next step to consider to aid students in consolidating the soft skills awareness of the students.

3.2.3 Participants

We would like to finish this first analysis of Technical Education with two short reflections about our participants — the students — that we described in 2.2.3.

This contribution gathers a number of instances, policies and plausible arguments that have been made in favour of bridging what we called the disconnect between CS education and the "real world". We are far, however, from seeing the ideas discussed here become widely adopted.

Students perceive this clearly: our interventions are directed towards Master's students, and when students reach this point in their academic career, most of their ideas are already formed.

We want to highlight here two recurring ideas that are frequent in CS students and that we believe are contributing to the disconnect between

CS and the real world.

The first reflection, on the role of specialists, aims to highlight some of the paradoxes behind the conception that specialist knowledge is to be preferred to generalist knowledge; a briefer second reflection, on employment perspectives, wishes to summarise a few key mismatches between what is expected or desired *of* CS professionals, and what is expected or desired *by* them.

On specialist knowledge

There is a perceived duality between so-called "generalist" knowledge and "specialist" knowledge. Policy-wise, the dominating narrative for *cs* education, and engineering education more broadly, has been that of the *T-Shaped* (or *teeth-shaped*) engineers [222].

The core idea behind T/teeth-shaped engineers is that engineers should be trained both in general knowledge (the horizontal part of the T), and should then specialise in one sub-domain (the vertical part). We wish however to challenge this model, focusing our attention on the *horizontal* component.

> Are we sure that the "horizontal" component of the T/teeth is, indeed, horizontal?

We wish to make an argument here (aligned with Tranquillo's — see [222]) for the fact that, as knowledge hyper-specialises, what seems like an horizontal is, in fact the combination of many shallow verticals.

Figure 3.5 exemplifies our argument: the horizontal component of one such engineers can be, in fact, another's — decontextualised — vertical! In other words, if universities wish to deliver on the horizontal component of the "T", they need to provide courses specifically designed to develop their students' breadth.

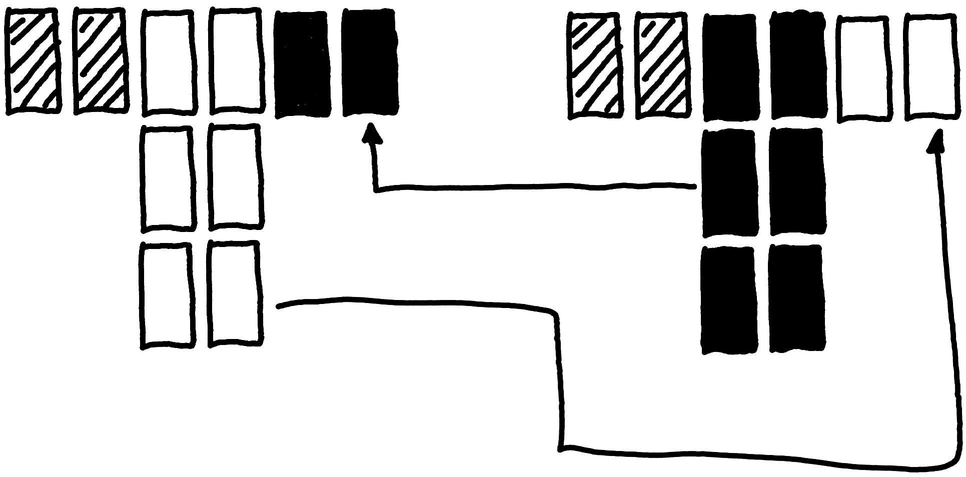

Figure 3.5: One of the issues of "T-Shaped" curricula: a student's specialization course might be positioned as another's generic course. Basics courses in a specialisation track, however, might not be adequate to form a general view of a subject for a student specialising in another field. The different colourings represent different specialisation tracks.

Today, this is often done by offering introductory courses to students specialising in other (sub-)disciplines. The first course in a specialisation path, however, is not necessarily the best course to give a general view of a subject that might be needed for a generalist profile. The result of this curriculum design is that today's computer scientists are often deeply-trained specialists in one field, and superficially-trained specialists in a handful of other fields. Other disciplines face similar challenges: most obviously, perhaps, medicine.

While medicine has not fully solved this problem, there is a situation we are familiar with: doctors work in *equipes*, so much so that most of the research in "interdisciplinary collaboration" actually involves collaboration between doctors of different specialisations. But who holds a broader, systemic view?

We wish here to highlight that there is a need for *actual* CS generalists. Forays in I&E show how CS professionals are increasingly asked to take a variety of roles in the industry. Some hints of this trend have been discussed as far back as 1999 [184] are starting to appear in the broader society (see, for example, [21] and [169]), but the limited inclusion of deeply interdisciplinary subjects in CS curricula shows how this trend is still at an early stage

We observe the effects of this trend towards hyper-specialisation on the countless times when a task is deferred to a supposedly better-trained specialist, and when those specialists fail to notice high-level issues, sometimes with catastrophic consequences [214].

Aside from improving generalist skill sets — and designing curricula that aid to accomplish this — a further opportunity rises from the last decade of advancements in Artificial Intelligence (AI). As current AI systems are increasingly able to solve extremely narrow specialist problems (often, better than humans), we have the opportunity to think about how human intelligence can complement machine intelligence.

Some key trends in this sense are the ones discussing AI *explainability* [81], and research exploring issues of problematisation and interdisciplinary research. For all the talk about STEAM disciplines, the scientific discourse can in this sense learn much from the humanities.

Employment perspectives

Some consideration should be also given to the perception of values in CS professionals' work places.

Reports such as the World Economic Forum's "Future of Jobs" [83] highlight that the jobs market is looking for employees that are trained on a number of what we have classified as "soft skills". The report emphasises, among many, the need for critical thinking, self-management, and working with people.

Similarly, in the academic context, work such as Verma's [228] shows how a majority of jobs posting, even in apparently highly technical fields such as machine learning have an explicit requirement for soft skills, at a very minimum in the form of (self-)managerial skills, but often also in terms of communication, interpersonal, and problem solving skills.

In spite of this, work such as Steiner's [205] or Belski's [24] suggests that universities are not delivering enough on equipping students with the skills they need and that students show a low interest for these skills.

So what can we make of this mismatch? We argue that much of it comes out of a form of "generational anxiety" that the current generation is facing (see, for example, [199]). Nonetheless, we think these two trends should not be opposed: CS professionals can have the qualities that policymakers and employers seek while also trading off with the values they hold.

In order to do this, however, students need to be better equipped at understanding these trade-offs and values which, in turn requires universities to increase their explicit commitment to this agenda, teaching subjects such as ethics (see 3.2.1), as well as by embedding the development of these skills in the courses they teach.

Our main instantiation goes exactly in this direction, attempting to develop at the same time a critical understanding of technology, while increasing direct interactions between students.

3.2.4 Instantiations

3.2.5 Using teaching methods to address broad technical challenges

In this section, we present the first conceptualisation of the "Technology Battles" teaching methodology.

This is an adaptation with minor modifications of our previous work published as *'A Constructivist Redesign of a Graduate-level CS Course to Address Content Obsolescence and Student Motivation'* (see publication list at 1.4).

Abstract

The last decade has seen a rising popularity of active learning methodologies in CS, empowering students and developing their soft skills as well as their technical knowledge. In parallel, the speed of technological obsolescence also increased, creating challenges for teachers to keep their course content fresh and up to date. In this paper, we present a constructivist redesign of a Graduate-level laboratory course in Web Service Design and Engineering that leverages latent pockets of student knowledge to tackle these challenges through Learning by Teaching (LbT). We illustrate how such redesign was planned, deployed and evaluated, highlighting the guiding role of teachers in the process and discussing how this approach was able to solve the problem of keeping content updated while broadening both content and tools students were exposed to. Furthermore, we will discuss how the additional motivation stemming from their empowerment allowed students not only to perform more work compared to a lecture-based implementation, but also to perceive it in the end as a lesser load.

Introduction

Constructivist education has enjoyed relatively high popularity in the past decades[8], with its applications mostly focused towards younger learners [172]. In CS in particular, constructivist pedagogies have been deployed successfully, applying models such as challenge-based learning [159][182], team-based learning [147][116], and, in a constructionist derivation, FabLearn [103].

A parallel phenomenon to this pedagogical evolution, however, has been an accelerating speed in the evolution — and therefore also obsolescence — of the technologies used in CS. The World-Wide Web and its tools, which represent the context of our course, have been no exception to this. As these technologies evolve, HE Institutions need to update their curricula to make sure that what they are teaching is current, relevant, and useful for students when they enter the jobs market.

Some technologies and programming languages have remained in the last years relatively stable in popularity [44], and have become the backbone of many HE courses. Nonetheless, industry constantly asks for candidates to be trained in different technologies [221], and not necessarily the aforementioned "evergreens". Because of this, it makes sense for HE Institutions to expose their students to these trending technologies, though constantly updating courses to use flavour-of-the-year technologies would be cumbersome and impractical. Frequently changing programming languages taught in courses to follow trends might also create issues where — because of fast technological obsolescence — what students learn obsolesces quickly, lowering the value of the educational experience.

Nonetheless, the rise of online learning platforms such as Codecademy[9], but also edX and Coursera, shows that students and young professionals do have an interest in keeping up to date with trends, and are even willing to use their free time for this purpose.

In this paper, we will discuss how we redesigned a programming laboratory course on "Web Service Design and Engineering" through a constructivist framework. The course did not change its core content, overarching structure or LOs, but instead implemented a form of Active Learning, giving students more freedom in implementing their final projects, while keeping the same formal requirements as previous years. Starting from a reflection inspired by ANT, we sought to detach the course from its originally-adopted programming language and ground it instead on students' expertise and interests, with the goal of making the experience more

[9] `https://www.codecademy.com/`

updated and engaging.

In practice, students worked in teams to teach to their peers a laboratory class, and then formed different teams to work on the projects. During both phases, they were able to propose whatever tool or programming language they deemed suitable or interesting for the tasks they wanted to tackle. In labs, they were also encouraged to propose additional content that they thought would be relevant for the course and, in projects, they were asked to propose themes that would be useful in their own workflows and daily lives.

In the following sections, we will first provide a brief overview of related work, focusing in particular on the theoretical grounding of ANT and, in the practice, on active learning and LbT experiences; we will then describe our implementation and the setup for measuring the outcomes of this redesign; we will later illustrate the main results, and finally provide conclusions and outline opportunities for further exploration of the outcomes of this experience.

Related Work

This study is positioned at the intersection of two different segments of the broader topic of constructivist pedagogies. Epistemologically, we draw the grounding of our study from the understanding of Actor–Network Theory in education, while methodologically, we adopt the practices of Learning by Teaching.

ANT as a tool can be used to describe how the relationships between human actors are affected and shaped by non–humans (and their interrelations) [127]. One such key relationship is that where humans treat technical artifacts as "black boxes" which, when deeply nested and accumulated, require substantial effort to be unpacked [124]. In ANT, black–boxed non–human actors are also attributed with "agency", as they become able to concretely affect relationships between humans [183], as if the actions they allow or disallow represent the actions of these non–humans. This form of agency, it can be argued, can be traced back to the designer's intent embedded in technological artifacts [126].

CS classes are naturally full of tangible and intangible technological artifacts or, in ANT terms, designed non–humans. The idea of applying ANT to the field of education has been most thoroughly explored by Fenwick and Edwards [79]. Of particular interest for our discussion is that in the views of Fenwick and Edwards, the curriculum is reified (and thus black–boxed) holistically, along with the non–humans it employs as part of its design. In the context of a programming course, programming languages become one of the key tools enabling the process of translation [42] of theory into learned practice. In this sense, technological tools in a programming course are embedded — or rather, in–scribed [6] — in the course, and become part of the black box.

Our action aims at carrying out a process of de–scription [5] of languages and tools from the course, including in its stead tools brought by the students themselves. This, we hypothesised, could reduce the effort required by the students to unpack the black boxes, if nothing else because tools are now familiar. The way we enable this process is by letting students teach parts of the course, namely the lab sessions. Empowering the students in this way puts them on the same side as the teachers in defining the relationships in the class' actor–network and enables them to truly enrol the technologies to serve their learning. A summary of this process of de-scription can be found in Figure 3.7.

While Active Learning (AL) has been a popular concept lately, its penetration in the STEM education field, and in particular in CS, is still relatively low [92]. Learning by Teaching is a form of AL originally developed for the teaching of foreign languages, which has most recently been the focus of the research activity of Grzega [94]. LbT has been called an effective way for students not only to more effectively retain course content [93], but also to develop soft skills such as communication [15].

Other forms of AL have been successfully used in universities [84], especially with the goal of improving engagement. In CS, the most common examples are forms of *Learning by Doing (LbD)* such as Problem–Based Learning (PBL). Nonetheless, a study by Okita [157] shows that LbT has lasting effect on student learning, even sometimes outlasting those of LbD. In parallel, it has been noted that students of CS are increasingly using their free time to develop personal projects and learn new tools [145], and are drawing strong motivation from these endeavours [144].

This last phenomenon implies that the classroom space increasingly contains pockets of latent or tacit knowledge which are not tapped by lecturing. Other contexts such as those of makerspaces have proven to be well-suited for these purposes, with studies showing how the mode of learning (formal, non-formal, informal) affects knowledge generation and transmission [69], but this remains a relatively inexplored topic in HE classroom teaching.

Transmission of formal and tacit knowledge, nonetheless, are radically different matters [229]. In this sense, as it is typical for AL processes, the role of the teacher as a guiding mentor and a facilitator is key [15]. To illustrate this in ANT terms, we can say that the teacher can use pedagogy (LbT) to enrol students and their knowledge to assist the process of de–scription of the non–humans normally embedded in courses, and achieve our design goals.

Implementation

When we started redesigning the course, we set one main overarching goal: we wanted to see if a radical empowerment of students could be used to increase the relevance of the course's content while promoting more active engagement at the same time. We also defined two ancillary goals: first, we expected that the new course structure would lend itself naturally to the development of student soft skills; second, we wanted to guide students toward creating content packages that would be reusable by future cohorts. These two ancillary goals were not addressed in this first run, and instead we wanted to observe if students also saw these opportunities.

Context

Our course involved a total of 24 students, 19 attending and 5 non- attending. The experience we report here focuses on the attending students, since they are the ones that were tasked to deliver the lab session to their peers. Non-attending students were asked to deliver the same material that went into the preparation of a lab session in a mock presentation to the teachers during their exam, but we will not discuss their case, since it lacks the fundamental student-to-student peer instruction.

The course took place twice a week in lectures of two hours each in a university in Northern Italy from September to December of 2018, and was entirely taught in English. 13 of the attending students were Italian, and 6 were international students. The teaching team was composed of one professor, a PhD student tasked with developing the lab methodology and mentoring for the labs and projects, and a post-doc researcher that was tasked mostly with technical mentoring for the labs and projects. The course lasted a total of 23 sessions of 2 hours each, of which 6 were dedicated to theory; 7 to the labs; 3 to plenary mentoring sessions for the labs; 4 to plenary mentoring sessions for the projects, and 3 to the course introduction, wrap-up and in itinere testing on the theory part.

The course's theory lectures were divided in four blocks: (1) a high-level introduction; (2) data representation, marshalling and exchange (XML and

JSON); (3) service engineering techniques (REST and an introduction to SOAP); (4) designing and deploying service architectures. The labs sessions were partly pre-determined mirroring theory lectures (XML; JSON; Testing; writing REST services) and partly new topics proposed by students and validated with the teaching team (virtualization and microservices[10]; automated Documentation; Authentication and Authorization). For all labs, students were able to propose not only the flow of the session (number and difficulty of exercises, instruction style, coaching method etc.) but also, centrally, they were free to choose any programming languages or tools that they deemed were the most appropriate or interesting, as long as they provided adequate background information to their peers to be able to follow the session. Similarly, for final projects, students only had a document with loose guidelines, and were asked to propose their own topic and architecture, as long as it satisfied a number of given technical constraints.

For this article, we will focus on an analysis of the labs and how their workflow was established. This is both because labs were the centrepiece of the course and because theory was kept with no difference from the previous implementation, and projects kept the same guidelines, except that students were also asked with ideation and choosing their implementation tools.

Lab Workflow

On the third lecture, students were introduced to the general workflow of the labs (which we will briefly present here and summarise at Fig. 3.6) and the pre-determined lab topics.

Students were given two weeks to autonomously form groups of 2–3 students and select or propose lab topics, each team bidding on up to

[10]Introducing Docker as the main tool and use case.

two topics they would be interested in preparing. Two weeks later, the bidding phase was concluded in a plenary session where teams negotiated together the final distribution of lab topics, and lab slots were assigned on the course's calendar, starting two more weeks from that date.

From here, each team went through the same pipeline:

1. Drafting session
    - *Format*: Informal discussion in office hours after class time.
    - Students propose a high-level session outline to the teachers.
    - Exchange of immediate feedback on broad changes that need to be made.
    - Scheduling of a meeting for the first mentoring session.
    - *Timing*: At least two weeks before final lab time.
2. First mentoring session
    - *Format*: Ad-hoc scheduled meeting of 1 hour.
    - Students present a more detailed overview of the lab session.
    - High-level presentation of theory, exercises, tools, etc.
    - Discussion on session content, mode of delivery and presentation content.
    - If major revisions are needed, a second mentoring session is scheduled. If only incremental improvement is necessary, the Dry Run is scheduled instead.
    - *Timing*: Two weeks before final lab time.
3. Second mentoring session (optional)
    - *Format*: Ad-hoc scheduled meeting of 1 hour.

- Same mode as the first mentoring session, but focusing on any necessary improvements.
- At the end of the session, the Dry Run is scheduled.
- *Timing*: Between two and one weeks before final lab time.

4. Dry run

   - *Format*: Ad-hoc scheduled meeting of 1 hour.
   - Students perform a mock run of the session in front of the teachers.
   - All environments need to be ready and working, slides need to be in a final draft state, exercises are skipped to expedite the dry run and only discussed.
   - Fine-grained feedback from the teachers both on technical content and on presentation/delivery modes.
   - *Timing*: At least three days before final lab time.

5. Lab package delivery

   - *Format*: e-mail
   - Delivery of an e-mail containing the final “lab package” (see below).
   - Circulation of the lab package by the teachers.
   - Students participating to the session are expected to download the lab package and install the environment to be ready at the start of the session.
   - *Timing*: At least 24 hours before their sessions.

Each lab package was designed to be used in the class, but also as study material to be used at home by absent peers, non-attending students, those needing to revise and, ideally, also future cohorts. Each team had to deliver

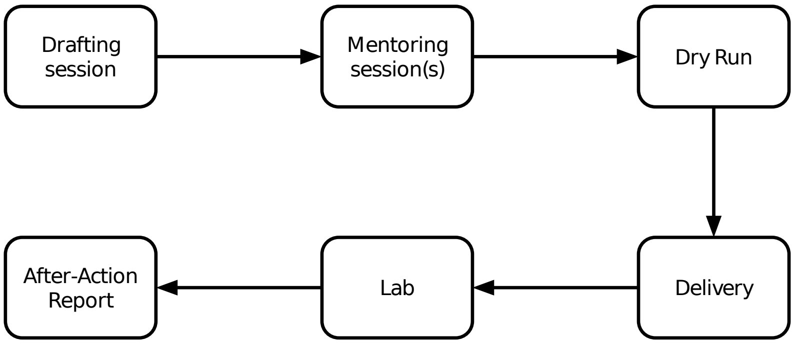

Figure 3.6: A visualisation of the flow of each laboratory.

an "environment" which was either made of a VirtualBox VM containing all the necessary tools to perform the exercises in the sessions or, when the lab only used web-based tools, a document with links to those tools.

Each lab also required a set of slides that students would use to support their in-class presentation, which could possibly be made different between slides for attending and non-attending students. Slides should contain all theoretical/background information needed to follow the session — focusing especially on content not covered during the lectures — and a set of exercises, of which one — longer — designed as a take-at-home exercise. Finally, since students had the option to introduce new technologies that could be unfamiliar to their peers, they were asked to deliver a one-page "cheat sheet" summarizing all necessary syntax and key commands used in the session. These lab packages were published on the course website as soon as they had been received from the teams.

During the lab, students conducted their session with no intervention by the lecturers, which also followed the labs as if they were students. Teams were given full freedom on how to teach their class, also deciding who in the team would speak and present, and how to support their peers.

Immediately after the class, all attending students were asked to fill an anonymous questionnaire on Google Forms, which served as our main way to evaluate the success of the labs. We will present the questionnaire in more detail in section 3.2.5. In parallel, each teacher also gave an evaluation of the lab for the purpose of grading. Dimensions evaluated by the teachers were the quality of (i) background information; (ii) materials; and (iii) exercises. Each dimension was evaluated on a 1–10 scale, and complemented with comments. In the week after their session, teams were finally asked to reflect on their own experience through a non-evaluated one-page document that we call an After–Action Report (AAR). This will also be illustrated further.

Course Element	Scoring weight
Test on grounding theory	30% of final mark
Lab session	30% of final mark
Peer-evaluation of lab session	Up to +2 points on lab score
Final project	40% of final mark
After-Action Report	Not evaluated

Table 3.1: The deliverables and mark weight for the SDE course.

Evaluation Tools

To evaluate the success of our redesign, we relied on three main tools: Student Evaluation of Teaching Questionnaires (SET Questionnaires), Lab Questionnaires (LQs) and AARs.

The first, SET Questionnaires, are the standard anonymous evaluation of teaching questionnaires that all students have to fill at the end of a course in Italy. The SET Questionnaire has been developed by the Italian National Agency for the Evaluation of University and Research (ANVUR) following the European ESG standard [77]. While similar instruments have been in the past criticised, especially for not being able to accurately evaluate faculty's teaching effectiveness [226], we decided to still use them for two reasons: first, they represent our only source of constant historical data, since they have been gathered since the course's inception in its previous design; second, we are using SET Questionnaires not as a tool to directly evaluate our intervention, but to discuss their most literal interpretation, namely student *perceptions*. A sample SET Questionnaire with the same questions as the one used in this course can be found at [3] [4].

The second tool, the Lab Questionnaire, has been developed *ad–hoc* for this course. It is a Google Form document with 10 mandatory questions using a 1–5 Likert Scale, with 5 being high, plus two optional open questions. The questions evaluated dimensions such as engagement, quality of the presentation, quality of materials, difficulty progression, use of class time, and perceived usefulness. A Likert question also asked students to self-evaluate previous knowledge on the lab's topic to filter out potential biases. The two open questions simply asked what was the most valuable aspect of the lab and what were points of improvement.

Questionnaires were delivered in anonymous form, using Google Forms' authentication to ensure that each student would only submit one response, and a narrow opening window to reduce chances of tampering and external influences. Students were encouraged to fill LQs at the end of each lab session they attended, and their presence was tracked in-person. Cross-checking the number of questionnaire responses with the number and testimony of present students allowed to preserve anonymity and avoid pollution of the data from external actors. Each student had to attend at least 5 out of 7 lab sessions (including theirs) to be considered attending.

Finally, the last tool was a written one-page group document, called the AAR. Here, we asked students to tell us: (i) what they think worked; (ii) what did not work; (iii) what they learned from the experience; and (iv) what they would change if they were to do the session again. The goal of this tool was to have a written trace of the perspective of the student-lecturers so that, in case a session would be controversial, we would be able to see both sides. Lastly, the AARs also gave us a way to gather insights on the teams' own sensemaking of the process they participated in.

Results

To analyse the results of our intervention, we will address separately the three main evaluation tools that were used: the first, the SET Questionnaires, will serve as a longitudinal tool to evaluate how student perceived the course across the years; the second, the LQs, allows us to observe more closely perceptions tied to each session; the third, the AARs, will be used to gather additional insights on critical aspects that might have arisen, and to draw general observations on how the students perceived their "role reversal" from listeners to leaders in the class.

It should be noticed that, for the longitudinal element, the course maintained the same lecture materials and project structure, with only minimal changes from year to year. Lab sessions were roughly equal in amount as the revised implementation, but used a completely different format. Previously, each session was a 2–hours tutorial where the Teaching Assistant (TA) would guide students through a set of exercises done in Java using the Eclipse IDE, along with a number of other tools. Attendance to the laboratories was not tracked, and labs were divided in three blocks (data processing and marshalling; REST; SOAP) with a short assignment to be delivered two weeks after the end of each block.

SET Questionnaires

SET Questionnaires have been gathered since the beginning of the previous implementation of the course, which was run four times, from 2014 to 2017.

As far as general appreciation of the course is concerned, the course was generally well-received, with only 2016 being particularly critical. In the four years, student satisfaction is at 93.5%, 95.2%, 68.0%, and 92.3%.

The most critical metric in SET Questionnaires, however, is the one related to perceived load of the course. Students feeling that the load of the course is balanced with the number of awarded credits is 61.3% in 2014, 76.2% in 2015, 52.0% in 2016 and 84.6% in 2017. This is consistently the lowest score the course receives in SET Questionnaires.

Since 2016, students also started suggesting to improve the quality of teaching materials. While 2014 and 2015 had all students satisfied about the quality of the teaching material, 2016 and 2017 report 80% and 84.6% of the students being satisfied, despite the material remaining the same. In 2016, many students also report in the open feedback section of the SET Questionnaires difficulties in configuring and using the lab and project environment.

The 2018 implementation seems to have solved these issues. In the 2018 SET Questionnaires, all students report being satisfied with the course, all students thought the load was balanced with the number of awarded credits, and that the teaching material was adequate. The only critical remark received in SET Questionnaires is in the open feedback section, where one student states that "student-led lab lectures need to be more consistent [sic]".

Lab Questionnaires

In LQs, the highest measures obtained are those of the support materials, Virtual Machines (VMs), and exercises, averaging 4.57, 4.56 and 4.53 out of 5 on the Likert scale. The lowest is the one for engagement, which is however still at 3.99 on average.

The measure of "previous knowledge on the topic" also allows us to identify topics where students feel stronger or weaker. Here, JSON and

XML seem to be the topics where students were most familiar (3.36 and 2.82 respectively), and Virtualization was the least familiar topic (1.91).

The Virtualization lab was also, overall, the lowest-rated session, while still having an average of 3.98 across the measured metrics. Exercises have been particularly critical, with students noting in the open questions that the progression was at times too flat and at times too fast. The best-rated lab was instead the one on Authentication, especially on the engagement metric (4.50), with only a remark to give more time for exercises. These evaluations, and all overall evaluations given by students, do not significantly differ from those given independently by the course lecturers.

Reading the answers to the open questions, students clearly appreciated the variety of technologies and tools that were introduced, with many students stating that they were seeing them for the first time. Most requests for improvements, on the other hand, focus on the need to have a clear difficulty progression in exercises and, in general, stronger guidance during exercises.

Labs that introduced technologies that were unfamiliar to the class raised division: the Virtualization, REST and Documentation lab in particular relied more heavily on specific tools, and answers to open questions show that students always noticed this, but were divided in stating whether this was overall positive or negative.

After–Action Reports

In AARs, all groups evaluated positively the experience of teaching to peers. Three groups also explicitly mention feeling like the experience was a good way to hone their presentation skills and learn the nuances that go into preparing lectures. All groups also made remarks correlating the pacing and progression of the exercises they proposed with how the class appeared to receive their lecture.

We also observed during the preparation sessions that teams introducing new technologies usually did so following the lead of one group member that was already interested in the chosen technology. In AARs, nonetheless, all teams that introduced new technologies report appreciating the opportunity of having to learn a new tool in enough depth to be able to explain it to their peers.

Three groups also say that, if it were possible, they would have preferred to have more time in each lab session to go more in depth.

Finally, the Authentication lab team reflects on their (relatively heavy) use of comedy in the form of "memes" as a mean to engage the class. In their AAR, the team states that they tried to use them to "express an opinion and improve participation", and that *"the small number of meme [sic.] reduced the impact of the lesson"*, something which LQ data seems to disprove.

Discussion

Different insights can be gathered, which we will present in four parts: (i) SET Questionnaires; (ii) LQs; (iii) AARs and (iv) general.

SET Questionnaires: the measure on perceived course load is particularly interesting. From a strictly quantitative perspective, the redesigned implementation did not reduce student load, and indeed, the redesigned course did not remove any topic covered in lectures or labs in the previous implementation. Project requirements also remained the same as the previous years, with the only difference that students were tasked to propose their own project rather than developing one assigned by the teachers.

With this in mind, it could be argued that the load on the student actually *increased*. Before the redesign, labs were used to exemplify theory and to learn the tools for the project. After, they acquired a bigger role, and required extra effort from the students to ideate, prepare teaching materials, and execute. Similarly, projects, which before were a pre-assigned exercise, required extra effort in ideation, which was moved from the teachers to the students and mentors.

These results can be read under the light of the fact that, in a way, the previous implementation ended up tying the subject-matter of the course (web services) to its implementation language, Java. In labs, the redesigned course flow definitely represented an increase in load both because of the added content (Virtualization introduced Docker, Automated Documentation and Authentication were not covered previously) and of the increase in tools and languages that the students were exposed to. In projects, the decision of letting students to be free to choose the implementation language and tools allowed them to reduce their load in a customised way, as students were encouraged to use the tools that they were the most familiar with, focusing on making sense of the content of the course rather than of the tools previously used by the course (Java and Eclipse).

When redesigning the course, we did not expect that students would perceive a decrease in load compared to the previous formula. If anything, we actually expected students to find the new implementation to be heavier, and that this would be a weakness of our model that we would need to address in the future as a point of improvement. We knew, from discussing with students of the previous years, that the Java and Eclipse environment was perceived as cumbersome and something that added extra complexity. What we did not expect was that removing this constraint and turning the choice of tools in the hands of the students would create so much slack in terms of perceived load. We also think that the added motivation given by the higher degree of empowerment afforded to the students helped them in tackling the extra challenge, but we do not have measures to help us back this claim.

Lab Questionnaires: labs have been overall evaluated positively. Some open questions stem from the LQ's outcomes, though. The highest measures — those related to class materials — are also those where, by nature, students have the least expertise to judge whether material is of actually good quality or not, since they are likely seeing that content for the first time. The lowest measure being engagement — while still being high — also suggests us that further exploration on our course model should attempt to use different measurement tools, since engagement is by its nature a more subjective matter, and thus something that students would be able to reliably report on. Nonetheless, the answers to the open questions, when given, have been constructive and shown attentiveness and insight, which makes us think that the questionnaire was taken seriously by students.

The introduction of new technologies seems to create a fine line between generating insight and confusion in students, and exercises appear to be the key in keeping the class engaged in the process. The Virtualization and REST sessions both introduced new technologies, but the comments on the Virtualization lab suggest that a non-smooth progression in the exercises made the class unable to draw strong conclusions on the lab content and the presented technology.

After–Action Reports: all students express a positive evaluation of the overhauled experience. Because of this, we think that the LbT represents a high added value of the course also from the perspective of the students, and could have a bigger place in the course's LOs as well as in its promotion in the department. The pacing of exercises also seems to be a main concern for groups reflecting on their own sessions, and observations in the AARs generally reflect those present in the open comments of LQs. The observations on soft skills made by the students also suggest us that students are aware of the importance of soft skills both in general and in the course. In general, the AARs seem to be an insightful yet somewhat superficial tool. A more structured template to guide reflection might help in making the obtained information more relevant, since the perspective of the student-lecturers is important in gathering a full picture of each lab session.

General: We provided an example of how a laboratory programming course can de-scribe programming languages from its core content. This has the net effect of emphasising theory and programming paradigms, re-framing the technologies used in the laboratories as instantiations of the paradigm rather than as self-standing techniques. By leveraging the silent technical knowledge present in the classroom through the students, the course remains relevant for a longer time, and obsolescence becomes a matter of programming paradigms rather than one of programming languages.

We also linked motivation with the perceived reduction in load that the students experienced. This, however, can become potentially problematic. Students report a lesser load compared to the previous implementation, but they are objectively required to perform more demanding tasks. Motivation in this sense can become a double-edged sword: it has the potential to reduce the perceived load, but motivated students might be led to situations of burnout [131]. To get more insight on the reduced perception of load, we can once again use the lens of ANT to look at the course as a whole. The design choices embedded in programming languages [126] affect how the students carry out their task, shaping how they think, and how subparts of a larger project interact, affecting also division of work. Students choosing their tools empowers them to reshape the relationships in the actor-network which the course represents, but this is a source of extra complexity and potential additional stress if tools are chosen unwisely.

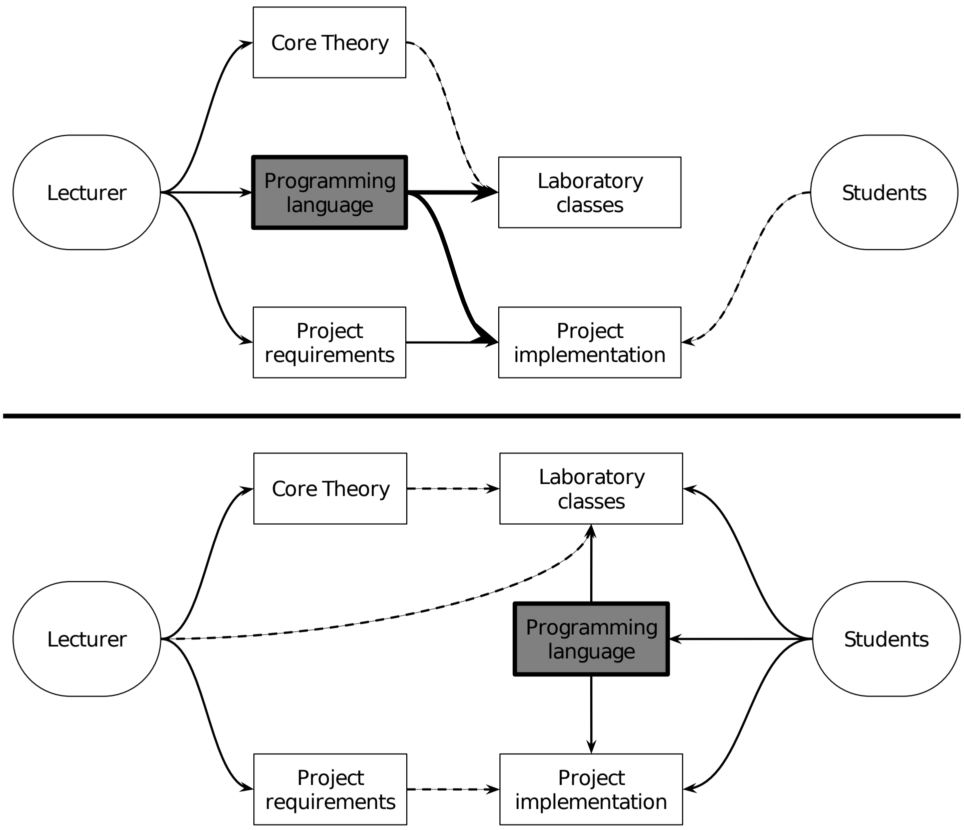

Figure 3.7: The result of the process of de-scription of the programming language. Notice how, by giving control to the students on the programming language, the students become empowered to co-define the project implementation, instead of simply having this imposed to them.

Conclusions and Future Work

In the previous sections, we illustrated how the course was redesigned from a formula based on traditional lectures to a structure that embraces a constructivist approach, empowering students to become co-owners of the classroom. We now wish to draw some conclusions from three main points of view: (i) LOs and skills; (ii) motivation and load; and (iii) scalability.

LOs and skills: the overhauled course implements the same core LOs, and asks the students to develop the same hard competences. A potentially relevant opportunity and field of future work, however, is that of using the course to explicitly address the development of soft skills such as communication, presentation, teamwork and leadership. From a "hard" skills perspective, instead, the assumption that it is desirable to have a more general view of a programming paradigm rather than specific knowledge of currently trending languages comes from informal discussion with students and companies. A systematic survey of whether this shift represents an added value in the market for potential employers or not also represents an opportunity for future research.

Motivation and load: we discussed how the perception of a heavy load was reduced in the overhauled implementation, though the load put on students was objectively higher. Empowered students surely enjoy the process more, but teachers need to pay extra attention to the consequences of the choices that students make. Different tools and styles of teaching the lab, to name two key choices, both affect how much time and energy students will need to invest in order to make sure that the laboratory will be successful.

Teachers need to have a strong ethical compass and develop a fine sense of empathy to push the students toward greater achievement while ensuring they are not overworking. This is particularly true for projects: if teachers misjudge the level of load of a project when students set their own tasks and decide their own tools, motivation might soon vanish. These reflections, here just stated as hypotheses and more general observations, are not formally explored in this article, and represent opportunities for further research.

Scalability: as this is a key challenge for many pedagogies alternative to lectures, we feel the need to draw conclusions in this sense. We think that our methodology would have worked better with a bigger class — around 30 students. This would have ensured that sessions were led by teams of around 4 students, giving capacity to the team leading the session to address questions and assist students experiencing difficulties. Surely, our approach can not scale indefinitely, since adding extra lab sessions also implies extra work from the teachers. A possible solution could be to split the class in two, so that labs are done in parallel by two teams to two subsets of the class, or to adopt a framework similar to micro-classes [7].

Another scalability concern stems from the idea that lab sessions should represent a package that can be reused by future cohorts as a source of extra exercises or more content. If this were to be adopted, we think there could be issues not only of incremental accretion of content (leading to heavier load), but also issues in taking questions about the material and evaluating it. In this sense, a framework of peer evaluation could represent a solution.

In conclusion, we think that our experiment — while at a small scale, with substantial room for improvement, and many untapped resources — represents a good example of how teachers can take concrete steps to lead students not as top-down managers, but as mentors and even, in the learning of new tools, as co-learners. As technology evolves and information spreads and decentralises, opportunities to create knowledge in the classroom space follow a similar path. If the role of the teacher is that of guiding students toward knowledge, we ought to teach our students not to look far away, but to look at their peers, and discover opportunities which are surprisingly close and humanly rich.

3.3 Fab Education

2002 marks the founding, at the MIT Center for Bits and Atoms, of the first "Fab Lab". Without delving excessively into details and nomenclature, we first need to provide an overview of what we present here as "fab education".

What we call "fab education" refers to the combination of two main elements: a physical facility (the laboratory) and a loose set of teaching methodologies. The name stems from the Fab Foundation, the non-profit organisation co-led by Neil Gershenfeld, the director of the MIT Center for Bits and Atoms, the most prominent figure in defining and promoting this form of education.

The laboratory is variably called "fabrication laboratory" ("fab lab"), "makerspace", "hackerspace", or other similar names. There is a massive diversity in these laboratories: some are commercial entities[11], some are embedded in public libraries[12], some are university facilities[13], some are self-standing community services[14]. At the highest level, these all are facilities containing tools and machines for rapid prototyping that are usable by the members of the community the laboratory is inserted in.

Teaching methodologies also vary greatly, but almost all such spaces tend to privilege a hands-on, "learning by doing" approach. Methodologies used in these spaces are often non-formal or informal in nature, favouring direct interaction between community members, and facilitating forms of teaching such as peer teaching and skills sharing [69].

Our discussion of fab education is contextualised in the space of the University of Trento, that had the chance to establish its own fab lab within

[11] For example, see `https://www.fablabs.io/labs/fablabvenezia`

[12] For example, there is one in the Oodi public library in Helsinki `https://www.oodihelsinki.fi/en/services-and-facilities/facilities/`

[13] For example, in Sorbonne: `http://fablab.sorbonne-universites.fr/`

[14] For example, see `https://www.fablabs.io/labs/fablabbcn`.

its premises. Our work focuses on the design of the general pedagogical model of the University of Trento Fab Lab, starting from the general problem space of creating a (physical) space to connect technical education with I&E.

Fab education does not hold a leading role in the context of this thesis. Nonetheless, we have spent a significant time exploring this space, and many of the key insights that are at the basis of our experiences in technical education and I&E education are inspired by fab education.

3.3.1 Why Fab Education?

There are a number of reasons that warrant the inclusion of fab education in a thesis with our aims. Most importantly, fab education is one of the few fields that *never* experienced the dominance of the traditional lecturing model.

The pedagogical methods deployed in the "How To Make (Almost) Anything" course[15] connect to MIT's tradition of constructionist education, highlighting the importance of hands-on learning. Epistemologically, this situates fab education as one of the few sub-fields of CS education that started from non-traditional pedagogies.

Fab education has also quickly situated itself as a space for interdisciplinary learning. While most of its content is about technology, fab education within HEIs has always historically connected technology with the arts and design, and fab education initiatives such as the Fab Academy[16] regularly welcome students from many different disciplines.

Another element of great importance in the space of fab education is the role of non-formal and informal learning. We have discussed in 3.2.2 potential alternatives to linear teacher-student relationships typical of for-

[15] See: `http://fab.cba.mit.edu/classes/MAS.863/`
[16] See `https://fabacademy.org/`

mal education: while young, the fab education tradition always promoted forms of peer-to-peer skill sharing and the gathering, exploration and creation of knowledge in less structured forms such as collaborative wikis, websites, and informal documents.

Finally, fab education has a strong vocation for community service. Our exploration of fab education has been tightly coupled with our vision of entrepreneurship as a deeply social endeavour. One of the limitations of I&E education, as we discussed in 2.2.1, is that it is often hard to translate ideas into practice, especially in ecosystems that are not as innovation-intensive as the Silicon Valley or the Boston area.

Fab education is seen, in the context of this thesis, as a way for many different actors in local communities to meet and create knowledge and artifacts in a collaborative space, strengthening the link between technologies, technologists, and the context they operate in.

3.3.2 A Fab Lab for the University of Trento

With these reflections in mind, we turned to the question of *how* we should instantiate them. This section will take a somewhat historical angle, retracing the steps that led to the development of the fab lab at the University of Trento. Of course, in alignment with this work's scoping, we will discuss here the *pedagogical and theoretical* reflections, leaving practicalities aside.

In early 2018, we were investigating how to better integrate our I&E offering with our technical courses. Quite quickly, one of the requirements that arose was to build something similar to a makerspace. The first conceptualisation involved two courses: the first would be an adaptation of an existing course focused on product design and development, ran in a makerspace-like environment; the second course would instead empower students in collectively developing, shaping and maintaining the lab used in the first course, creating a collective legacy for future students. We refer to this course as the "legacy course", and a visual draft of its base design is summarised in Figure 3.8.

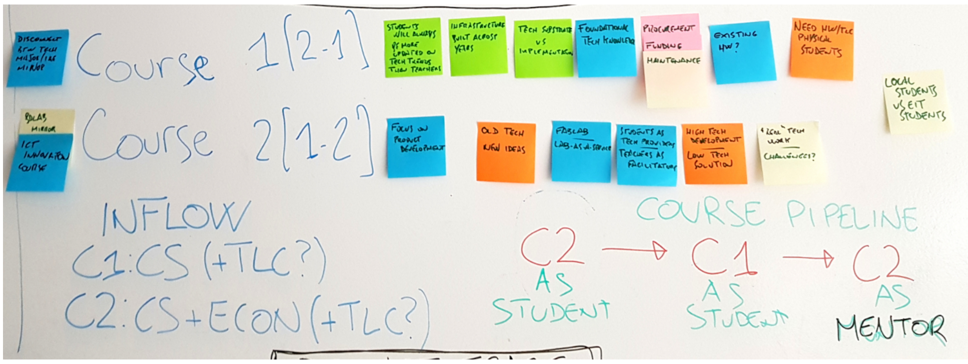

Figure 3.8: A first brainstorming that outlined the concept of the "legacy course". Notice that the course numbers are swapped compared to the description we gave above — the "legacy course" is referred to as "Course 1" in this picture.

The idea of a student-created legacy and crowd-sourcing knowledge and solutions eventually became at the basis of some of our interventions in technical education we presented in 3.2.2, and informed the design of the intervention described in 3.2.5.

In this same brainstorming phase, we also established the concept of peer-to-peer skill and expertise sharing as a fundamental intuition to bridge many of the knowledge gaps in students' technical education, and this element remained at the basis of the future design of the fab lab at the University of Trento.

The project was apparently cancelled after the presentation of the results of this first brainstorming phase. Then, at the end of 2018 (much to our surprise!), the project was restarted, with the official goal of creating a fab lab for the University.

The first half of 2019 saw the birth of a first iteration of the fab lab, which in the second half of 2019 was temporarily closed because of university renovations, and remained under (slow) construction for the whole of 2020 and the first half of 2021 as the COVID-19 pandemic reduced in-presence activities in the university.

That first half of 2019, however, has been extremely active. We summarise here some of the main interventions and contributions that we performed as part of our research work.

From a theoretical and conceptual standpoint, we explored the potential positioning of the laboratory in our university and territory's community (see sections 3.3.5 and 3.3.6). Practically, the lab started its activities by exploring one of the spaces discovered during our research: the intersection between analogue and traditional crafts, science and the arts.

This first experiment, conducted as a series of workshops, revolved around photography. The workshops started with a guest speaker discussing photography as a means of communication, and a hands-on workshop on post-production. More workshops, on 3D printing pinhole cameras, and developing photographic film, were developed but not delivered because of the lab's moving.

We mention here this first experiment not because of its high content significance, but as a symbol of the type of learning that the makerspace environment enables: peer-based, informal, involving local community members, open.

In other types of workshops, students taught each other "crash courses" in technologies they needed to use within their courses. When a Master's course required them to use this instrument, knowledgeable students taught in the fab lab a one-shot introduction session to the popular microcontroller platform Arduino as a way to bootstrap the learning process in their official course. This workshop was also attended by a number of students in their Bachelor's and of other departments, showcasing how a makerspace can be a flexible way to plug knowledge gaps in the *formal* education of a group of students, while *informally* building a community.

As the second half of 2021 starts, we now have a complete facility, and

Figure 3.9: A picture from one of the workshops held in the University's Fab Lab during early 2019. The students on the left were the workshop's main instructors and leaders.

the time is ripe to discuss what are the key opportunities that this space creates, especially under the light of its previous achievements.

3.3.3 Key Opportunities

To conclude this Side Story, we would like to draw a few conclusions from our previous space, and highlight what we think are the main opportunities that fab education provides in terms of "reconnecting computer science education with the world out there".

For fab education, we see three main impact avenues:

1. Strengthening the connection between CS and traditional crafts, and sciences and arts.
2. Complementing I&E education with hands-on practice.
3. Flexibly covering knowledge gaps in technology education curricula.

We will now briefly explore each of these, outlining the key takeaways and options for future work.

1. Bridging CS and crafts, sciences and arts. This is probably the most explored of all the reflections we are proposing at the end of this Side Story.

Many studies have discussed the potential of digital fabrication and makerspaces as a way to rethink the role of traditional crafts in our societies [69]. To the best of our knowledge, however, none have so far made the specific connection of linking makerspaces to a role of preserving cultural heritage (we discuss some conceptual possibilities about this in 3.3.6).

Furthermore, even if this connection were to be made, what remains unexplored is to discuss and investigate the pedagogical methods that could best support this process. This challenge is not just methodological in nature, but is deeply social and generational [89].

2. Complementing I&E education with hands-on practice. A substantial weakness of I&E education that is frequently brought up is that I&E is rooted on the Silicon Valley ecosystem of technology entrepreneurship.

Critics often point to two elements when discussing the low amount of startups in Europe: lack of funding, and lack of human capital.

Fab education has the potential to contribute to solve this second element. If it is true that Europe lags behind the US in term of hands-on experience of its engineers, then makerspaces offer the opportunities for students that are undertaking I&E training to prototype their ideas.

Additionally, makerspaces, when seen as educational avenues, have one more key advantage in Europe: the key competitive asset of the EU's HE ecosystem is the presence of numerous cooperation frameworks (see also 4.2). Makerspaces and fab labs have since their inception emphasised their networked structure[17].

[17] See for example how the Fab Foundation organises its Fab Lab Network `https://fabfoundation.org/global-community/`

So, what could happen when budding student-entrepreneurs get access not only to a network of laboratories for informal learning, but also to many networks of formal educational institutions? Navigating the complex graph of Europe's Higher Education space can become easier, and a major asset for entrepreneurial students.

This potential is — again, to the best of our knowledge — so far unexplored. We are investigating with some colleagues a first few potential forays in this space, as part of an Erasmus-funded project.

3. Flexibly covering knowledge gaps in technology education curricula. As the last reflection, we want to delve deeper into the potential of fab education to provide informal spaces to fill curricular knowledge gaps.

The Arduino workshops that we have piloted in early 2019 (see Fig. 3.9 in section 3.3.2) showcase what we mean by this. Curricular knowledge gaps might arise from a multitude of sources: from design mistakes, to implementation flaws, to simple "nice to know" skills that are not part of any formal course. Whatever their origin, these gaps undeniably exist and, much like in the case of course elements, there probably are students that could mentor their peers into covering these gaps (see 3.2.2).

In this sense, makerspaces offer the possibility of performing "rapid prototyping" not only of technological products, but also of educational materials and methodologies — material produced in successful workshops can then be adopted by relevant course teachers and integrated in formal curricula, fostering a system of co-creation and co-ownership of a HEI's educational offering between its teachers and its communities.

3.3.4 Instantiations

3.3.5 Designing the UniTrento Fab Lab

In this section, we present our first sketch of the principles that are at the basis of our Fab Lab, with a specific emphasis on how Fab Lab education should be adapted given the change in audience between "millennials" and "Generation Z".

This is an adaptation with minor modifications of our previous work published as *'Designing a Hands-on Learning Space for the New Generation'* (see publication list at 1.4).

Abstract

In this poster paper, we present a "design document" for a fab lab which is being developed at the University of Trento, in Italy. We will discuss why and how the space of the fab lab can be rethought for the generation of students currently in higher education, which, we argue, has different features than the one originally targeted by these structures. We discuss the three main design elements that we will use — combining high-tech with low-tech; constructivist education; and interdisciplinarity. Finally, we outline the relevant stakeholders for this type of initiative and how they can be empowered and integrated in the lab's architecture.

Introduction

Since their inception in 2001, fab labs have undergone many radical evolutions, one among many being the introduction of easy-to-use electronics prototyping platforms such as Arduino. The increased accessibility of technologies such as 3D printing, laser cutting, the aforementioned Arduino etc. has proven in this sense to be a critical asset for the success of the fab lab. This success particularly helped in accomplishing one of the fab lab's implicit missions: building awareness ("evangelisation") in its users of the opportunities that these technologies represent.

Additionally, many studies testify to the validity of fab labs as test beds for pedagogical experimentation and innovation, promoting a culture of hands-on learning and practice, especially in schools[111]. A subtle but substantial change happened in their user-base (i.e., the students), however. In universities, current cohorts are part of a completely different generation than the one that fab labs were originally designed for[171]. In 2001, MIT undergraduate students would on average be born between 1979 and 1983[18]. Currently, those students would be born between 1996 and 2000. This second group has grown up and lived with digital technologies being a pervasive reality in their lives. Therefore, – we argue – those might not be interested in this "evangelisation" dimension, but might be looking for a different educational gain from the fab lab setting than the original group.

This paper represents a "design document" for a fab lab that the authors are developing at the University of Trento, Italy. We will describe how we aspire at contributing to bridge the skills and generational gap between the current "high-tech" fabrication and traditional "low-tech" fabrication. We will describe how, for this model to be successful, students/users need to be strongly empowered. We will then have a brief overview of who are the stakeholders that need to be involved for this educational mission to be achieved, and draw some possible conclusions on what are the opportunities stemming from this view.

[18]Using an average enrolment age of 18 — estimate taken from `https://mitadmissions.org/apply/firstyear/international/`

Framework

We root our model on three pillars. These are not novel to the digital fabrication context. Instead, we believe that the space in the intersection between these three elements and the Higher Education context can be explored further. These are:

1. Matching high-tech with low-tech fabrication
2. Constructivist Education
3. Interdisciplinary Education

The first element stems from a reflection on the role of technology in the lives of the current cohort of students. As discussed before, students currently enrolled in university programmes were born in the late 1990s, and grew up accompanied daily by pervasive technologies.

This, combined with the devastating effects of the 2008 economic crisis, lead to a generation of students that does not need to be convinced about the applicability and impact of technology. The aim, instead, is to create a lab that brings “low-tech fabrication” skills in the Higher Education context. Examples of such skills might be handicrafts, professional crafts, and spatial reasoning. These competences are fundamental for many economic activities that were once dominant in our cities (and in Northern Italy in particular). These nowadays, however, are hardly represented in educational activities of universities. This is particularly true in ICT departments and curricula, which instead are the breeding ground for the affirmation of “high-tech” fabrication. From a practical point of view, a better integration of “low-tech” fabrication in the fab lab would allow students to move from conceptualization to prototypation with a lower technological barrier, while also broadening their skillset.

Filling this educational gap requires the deployment of pedagogical methods that allow for a free exploration of these subject-matters. Our design relies on a constructionist approach[8], which implies the need to challenge traditional trainer-student roles[41]. This can be seen as a source of extra complexity, but we deem this necessary because of two key factors. On the one hand, students (and especially those in ICT-related fields) are possibly more up-to-date with technological trends than their trainers, leading to a need to empower them more radically in order to deliver a relevant technology-based education. On the other hand, to deliver on low-tech fabrication, we will need to rely on experts which are likely not to be teachers. Both these challenges become less complex in a constructivist learning space, which unties the involved actors from their traditional roles (i.e., trainers as the only providers of knowledge; students as receivers of knowledge)[33].

Interdisciplinarity becomes a natural – and desireable – consequence of these first two elements. Fab labs are by their nature facilitators of idea generation and cross-pollination[206]. We think that this needs to be brought at the forefront of the learning mission of the fab lab, using the "making" as a field equalizer for students and experts, since nobody from a single discipline can possibly have the competences to take ownership of all processes that happen in this unique learning space.

The implementation of this framework requires the identification of all possible involved actors, and the establishment of an organizational structure flexible and resilient enough to guarantee a balanced representation of all the diverse expertises that contribute to the lab. What this means concretely, and who are the actors that we plan to involve is the subject of the next section.

Stakeholders

The plan to implement the framework elements outilned above requires an involvement of multiple stakeholders at different levels, from within and outside the university. We will briefly discuss their roles, starting from the internal ones.

First of all, for daily operations, we plan to rely on a solid backbone of volunteers (in our case mostly students). Beyond operations, however, volunteers are also seen as the main content providers, and are encouraged to use staff as providers of solutions to make their ideas for prototypes, events and workshops real. As we are operating in an university context, we need to be aware of the fact that individual students are likely not to remain in the university in the long term. This can be a problem – as it makes harder for individuals to contribute to the long-term growth of the lab – but also a resource. A fast rotation of volunteers helps keeping a steady flow of fresh ideas, and mitigates the risk of burnout, especially when students are under high load for other academic reasons.

We argue that coordinators and staff do not need to be subject to the same speed of rotation, and indeed might benefit from being more stable positions. Most crucially, the complexity of understanding procedures in the public administration means that, if staff were to rotate quickly, substantial effort would be spent in recovering procedural know-how. Additionally, however, long-term retainment of staff establishes clear figureheads and responsibility for external stakeholders that wish to support our initiative and allows to incrementally expand the lab's network rather than lose parts of it with departing staff. It should be stressed, however, that staff and coordinators are not the owners of the lab, and their main role is empowering the volunteers.

The final internal stakeholder are university departments. As we discussed in the previous section, one of our goals is to promote interdisciplinarity. This translates concretely in the need to involve as many departments as possible to participate in the creation of this learning space. Sharing this project not only ensures diversity, but also makes it more resilient, diversifying funding sources and catalyzing internal synergies.

External stakeholders are more heterogeneous, so they will only be given a cursory look. In this sense, the most important class is that of practicioners, both from the "high-" and the "low-tech" fields. Startups, innovation hubs, accelerators and foundations from the "high-tech" world that can support and benefit from the activity of the lab, gaining visibility, providing cases and challenges, and obtaining a more informal access to the talent pool of the university. Craftsmen, associations and groups of citizens on the other hand also benefit from the increased visibility, and act as gateways to those "low-tech" contexts that are less explored in their interactions with technology. Finally, local governments can act as network multipliers to broaden the reach of the lab.

Conclusions

At the turn of this decade, the model of the fab lab appears to be established and radicated, and many universities adopted it as a one of their facilities. However, we believe a strong focus should be placed on a reflection and revision of what their role is, especially as an educational space that should complement and enhance the teaching offer of higher education.

We argue that, as a side-effect of this reflection, some of the functions that fab labs perform might be put aside, to bring at the front one of the original goals of these spaces: providing students with a safe space for hands-on learning centered on skills and expertises that are not taught in their regular curricula. We argue that, in these times, this is particularly relevant for "low-tech" ideas and elements, to be explored in their combination with the "high-tech" fixtures of fab labs.

As the technologies featured in fab labs have matured, the opportunity rises to refine the value proposition of these spaces. They no longer are a privileged space in which 3D printers or laser cutters can be found, neither they are the cheapest or fastest prototyping facilities. Instead they remain, especially in their university incarnation, a rare context in which all these technologies and many others can be freely experimented with, without fear of heavy repercussions for failure.

By this perspective, the fab lab becomes not a space for “service” in the way that we commonly understood in the latest years (i.e., prototyping/electronics/cutting service), but a real “service” for the whole community that hosts them: from students, to universities, to enterprises. The opportunities stemming from this view are broad and powerful. As our societies face broadening skill gaps, increasingly difficult intergenerational dialogue and a culture of education which tends to work in silos, these laboratories can become a versatile link in the complex chain of human activities.

Poster

We also include here the paper’s poster, that was presented at the conference.

Figure 3.10: The conference's poster.

3.3.6 The "MILE Lab"

In this section, we present a slightly more mature view of the Fab Lab model that we presented in 3.3.5. We call this the "MILE Lab", focused on Making, Innovating, and LEarning.

This is an adaptation with minor modifications of our previous work published as *'A Conceptual Exploration in the Intersection of Crafts, Technology and Academia for Sustainable Job and Skills Development in the 21st Century'* (see publication list at 1.4).

Abstract

Since the beginning of the new millennium, the rise of the maker movement has sparked again interest in crafts in academia and high-tech industry. Some attempts at establishing collaborations have been tried, but have not solved the overarching problem of how our economy and society can find ways to cope with the perspective of technological unemployment. In this position paper, we propose a reflection, that leads to a model for a university laboratory that operates at the intersection of the three sectors of crafts, high-tech industry and academia. We outline a vision where each of these sectors contributes with its main strengths to the creation of a laboratory that lies at the intersection between Making, Innovating, and Learning, that we call the MILE Lab, that can aim to address the challenge at stake.

Introduction

With Artificial Intelligence widening its fields of application at an increasing speed, a similarly increasing number of jobs appears to be threatened by the perspective of the so-called technological unemployment [208]. This view is currently strongly debated [170], but one aspect remains factual:

some jobs are rotating out of the market, or have been otherwise significantly resized by the impact of automation. One such class of jobs is that of crafts [224].

The decline of crafts, it could be argued, started with industrialization almost two centuries ago. One of the side effects of digitalization, however, has been that of increasing economic inequality [120], which also contributed to this trend. The parallel increase in scholarization in the West [78][39] also reduced generational turnover in the field of crafts, since the newer generation saw those jobs as less attractive. The final tally leads to a situation where crafts are hardly at the center of the political, academic and economical discourse, and products of these activities have been by and large replaced by industrially-manufactured goods.

In this landscape, however, the arise of the maker movement can be seen as going against the trend. The vision of enabling rapid, accessible technology-powered crafting at small scale has gained substantial traction in the crafts, higher education and industrial sectors alike. The movement impacted all these sectors, and has recently also started to produce significant results in the education field, especially at the school level [103].

In this paper, we want to propose a reflection and a model for a university laboratory that operates at the intersection of the three sectors of crafts, high-tech industry and academia by leveraging the defining aspects of those areas. We will outline a vision whereby each sector contributes to a common vision, leading on their core area of expertise and supporting those of the other sectors. Mirroring the expansion of STEM to STEAM [123], the key advancement proposed in our model is that of enhancing university makerspaces by actively including craftsmen as co-designers and co-leaders of the process.

We will approach this task by first defining what are the problems of each of these sectors, focusing on how their job market operates and what skills they might need to remain sustainable in the digital era. For each sector, we will also look at what solutions have been attempted both on a per-sector basis and by grouping them in pairs and draw, making some critical considerations and highlighting where they could be improved. We will then briefly outline our model, and finally look at the limitations and potential impacts of our vision.

Problem Definition and Partial Solutions

In pre-industrial contexts, a large majority of the workforce was employed in farming, and crafts represented the more highly skilled segment of the labour market. Socially, this set them as a middle point between those that had to work to produce basic subsistence (farmers) and those that - in a form or another - employed workers (aristocrats). With the rise of industrialization, market demand for crafted goods decreased, making these jobs less attractive as a venue to economic stability.

Nonetheless, crafts kept developing well into the 1900s thanks, in greatest part, to the model through which skills used in the craft are transmitted, namely the master/apprentice relationship. Even this institution, however, has been disrupted by two key factors: first, as mentioned before, crafts became in general less lucrative and attractive as jobs; second, the rise of a competitive job market made the choice of working an unpaid apprenticeship position at a workshop usually a less interesting proposition than taking a job in the industrial sector. In spite of this, crafts have grown to be part of our human and social heritage, to the point where they have been ascribed as a category to be part of the UNESCO Intangible Heritages. Some of them, however, have also been flagged as "endangered" [224], due to the shrinking number of people able to perform these crafts and low generational turnover in spite of many efforts undertaken to consortiate and consolidate crafts at local or national level (for example, see

[146]).

Since the 2000s, the maker movement has revitalized the interest in crafts for the younger generation through the use of technology. The idea of combining the latest technologies with creativity and handcraft to create physical artifacts gained substantial traction. Crafts, however, have been mostly seen as something to be optimized through the use of technology, rather than a skillset with its own dignity. In other words, we could say that the maker movement has a tendency to "tech-wash" the crafts.

The same high-tech industry enabling the maker movement, however, isn't immune from the changes of the last years. Currently, industry employs a substantial amount of workers in lines such as clerical work and programming. These jobs have been recently framed as the most threatened by the perspective of technological unemployment [46]. Indeed, industry and academia alike recognize the need for engineers to develop a skillset which goes beyond technical skills [56]. Interestingly enough, some of these skills are integral parts of crafts, such as creativity and communication skills. To solve this, a great number of training programmes for young professionals have recently sprung as a way to complement academic education, offered by many heterogeneous organizations.

In parallel, academia has been facing the issue of making their educational offer more relevant to the jobs market and increase its mobility to industry and back [110]. In trying to fill industry demands, it focused its efforts on delivering technical skills, but the need of expanding academic education beyond such skills has been documented since the early 2000s in, for example, the EU's University Modernization Agenda [58]. In the European Union, substantial effort has been devoted to strengthening the ties between academia and industry to bridge the so-called innovation gap [243] through programmes such as the EIT, but there is no consensus yet as to the degree of their effectiveness. It should be noted that these collaborations have often seen innovation as the product of the cross-pollination between academia and industry, but have not involved crafts. Crafts are often involved as local stakeholders in lower level of educations (i.e., schools), but rarely they are involved in Higher Education. The general attitude toward crafts has seen the sector as one which is not academic enough, and especially not belonging to the much-sought STEM area.

The inclusion of Arts in STEM, however, creates a natural fit to deliver on the teaching of skills such as creativity by collaborating with those professionals that have historically pushed the boundaries of "applied creativity" in our societies. This trend also matches well with the pedagogical reflections of the last decade that have disrupted the traditional teacher/student roles in the classroom. Examples of these are methods based on experiential, project-based, hands-on learning. Indeed, as the speed of knowledge generation and obsolescence increases, all these methods have shown that changing the fundamental relationship of the classroom can be a powerful tool to provide more effective education. These settings also provide a scientifically validated playground in which craftsmen can attempt to disrupt the aforementioned master/apprentice relationship in novel ways.

If disruptions, and therefore innovations, are born in the boundaries between disciplines [204], the three-way boundary between these three sectors is one in which we can search for solutions that might be otherwise impossible if each sector approached this with a silos logic. We will now look at one possible model where such intersection can be created, and what solutions it opens to.

A possible complete solution

The solution spaces outlined above address the overarching problem in a "segmented" manner, but are insufficient to achieve a holistic solution.

Therefore, we argue that such a solution has to be constructed by drawing from all of the solution spaces outlined above at the same time.

In our view, each sector should contribute with their defining features: crafts are defined by non-repetitive work crossing over with arts; high-tech industry is defined by exponential growth in terms of product and process innovation; academia by its commitment to education and use of the scientific method.

Our proposed solution is a physical and metaphorical space that we call the "MILE Lab", a space for Making, Innovating and LEarning. This idea is modelled after a number of inspirations: the biggest is, for sure, the maker movement and Fab Labs, but we also see the MIT Media Lab, the Stanford d.school as inspirations. Each of the three sectors converging in the MILE Lab can be seen as the leader of one of its dimensions (crafts for making; high-tech industry for innovating; academia for learning), with the two others supporting and complementing the dimension leader.

Making, inspired by the crafts, should be unique and *artful*. If the core problem to be solved in crafts is that of creating resilient jobs, the focus should be put in the features of that work which are the hardest to replicate automatically. Namely, these are the artistic, creative and cultural aspects of crafts. This type of making, however, should also be *technology-aware*, to avoid repeating the errors of the past and ensure turnover and scalability of a craftsman's activity. This is where we envision the collaboration of industry, which can contribute bleeding-edge products and solutions. Academia also has a key role in ensuring that making is not done for its own sake, but has *purpose* (educationally, and in terms of skill acquisition). Making should be visionary and flexible enough not to be a mere application of currently available technologies, but instead seen as a process independent from the tech substrate, so that expertise acquired in the process can be adapted and applied in the future.

The view of innovation driven by the high-tech industry is *focused on the generation of value*, since businesses need to be sustainable. Our view of the MILE Lab also sees innovation as something that should be applied, and oriented to value generation (not necessarily in monetary terms, but also in terms of social, human and community value). In the duality of radical/incremental innovation, industry has been mainly focused on the incremental side. Integrating these "continuous improvement" processes into the architecture of the laboratory can add value to both crafts and academia. Academia, on the other hand, contributes to the innovation dimension by means of *interdisciplinarity*. Computer Science, Electronics, Design, Social research and many more academic disciplines all contribute to the implementation of the lab. The benefits of this interdisciplinary approach have been validated in terms of research, business, and especially education since the beginning of the 2000s [201]. The setting of the MILE Lab would allow industry to integrate these approaches to renew their commitment toward radical innovation.

Finally, the learning dimension is the true backbone of the MILE Lab. The main position that we want to take here is that learning in this lab should be *researched*. Epistemological stances, engagement strategies, teaching methods, outcomes and reflections should be documented and shared formally (e.g., through research papers) as well as informally (e.g., through whitepapers; workshops). We argue that our lab should follow educational models based on hands-on/experiential learning (which is also a key part of crafts) and divergent thinking (found in high-tech industry), but that these should nonetheless be subjected to the scientific method. Keeping this in mind allows to construct a framework for consolidation and incremental improvements to be put alongside the more disruptive approach that these learning strategies imply.

	Making	**Innovating**	**LEarning**
Crafts	Lead (creativity)	Support (human heritage)	Support (hands-on learning)
High-tech Industry	Support (enabling solutions)	Lead (value generation)	Support (incremental, explorative learning)
Academia	Support (skill acquisition)	Support (interdisciplinarity)	Lead (education research)

Table 3.2: A summary of the three sectors and areas of intervention of the MILE Lab, highlighting which sector leads on which area of intervention.

Conclusions

In drawing some preliminary conclusions about this reflection, a first limitation comes to mind: our model for the MILE Lab ends up framing, at the end, an exercise which is still driven by academia. It would be interesting to discuss a similar model where the lab's leadership is left to crafts or industry. The main problem in this case, however, would be ensuring that the organization taking the lead has enough manpower and capacity to commit to pursuing the goals of the laboratory as a whole together with their own goals. Another key factor that favours academia taking the lead is the fact that universities have a much longer lifetime as organizations than both workshops and companies.

In conclusion, with our reflection we aimed at drawing the attention at what we feel are some missing links of the models that we have taken as inspiration. In particular: 1) bringing the artistic part of crafts in the dialectics of technology-enabled making provides us a way to train students and construct jobs that are by construction harder to replace with machine; 2) the focus on value generation in such hybrid context makes this an exercise not just in creating a novel experimentation space, but one that - through its alumni - can one day feed back into the economy; 3) researching education both in a formal and informal way hopes to break one of the deadlocks that our field is facing, namely the fact that studies can be either scientifically meaningful or visionary, but hardly both.

Chapter 4

The World Out There

4.1 Introduction

Change is, often, an extremely slow process. The actions we have presented in this thesis represent a step in a process of change that started several decades back. Action on the ground is often, in practice, preceded by substantial research work carried out by national and sovra-national actors by the means of policy.

This chapter has a different nature to the ones presented before: rather than discussing the landscape in a (sub)discipline, we want to take a step back from implementation work. Ultimately, we aim to reflect and explore how our actions can be situated in the European and global landscape. Our goal in this (shorter) Chapter is to outline the origins of these actions, and what could be their future, by discussing the relevant policy they connect to.

> Policy, in an essence, is our lens to interpret how global governments see our World. By discussing relevant pieces of policy, we can see how the field of CS education is orchestrated at the highest level. Policy becomes a time machine, re-framing yesterday's ambitions as today's goals and tomorrow's achievements.

Our policy context in this thesis is that of the EU. This choice is due to three factors: first and most trivially, our research work was conducted in the EU; second, each of our research actions fitted into EU policy — often as part of an EU-funded project; third, and most importantly, the decentralised model underlying EU policy opens unique opportunities to, at the same time, coordinate strategies and distribute risk. In other words, EU policy is an enabler to be more entrepreneurial-minded in approaching the evolution of (CS) education.

This work does not want to position itself as EU–centric to the point of arguing for the superiority of the EU as an experimental context. Nonetheless, as we cannot deny that this work is EU–*centered*, we wish to seize this opportunity, and explore deeper the implications and opportunities that this context enables.

In our work on the "Technology Battles" 2.4.1, we have argued that contexts can be designed so that they superficially appear to be competitive, but are at a deeper level collaborative. The EU's HE system, with its countless forms of cooperation opportunities, represents such a dual competitive/cooperative setting. Universities *compete* to acquire grants for *collaboration*.

This system is not without flaws: even a simple glance at relevant statistics on Eurostat highlights how the system tends to create reinforcement loops, where those who win keep winning, and those who lose keep losing [75]. While these and more fair criticism exists, it is hard to deny that the EU has succeeded in creating a structure for research and education collaboration spanning an entire continent, and impacting the whole world.

One of the most frequent criticisms of this model, however, is the EU's assumed inability to deliver innovation to the market, especially when compared to other global knowledge hubs such as the US [180]. We can find an alternative interpretation of this phenomenon, once again, in Mariana Mazzucato's work, summarised in "The Entrepreneurial State" [143]. Paraphrasing:

> The public sector — here represented by the EU — often takes risks *far greater* than those that are commonly attributed to VCs and the private sector.

In education, where research has the additional challenge of a complex sense- making of its results, this is even more apparent: a sovra-national body such as the EU is in the best position to pioneer actions that might not be as transformative as they were hoped, or might be not cost-effective.

This is, of course, not to say that risks should be taken carelessly, or that the public sector should not strive to be successful. Quite on the opposite, as resources directed to these efforts are coming from the work of all EU citizens, HE cooperation policy should be crafted with the highest of ambitions.

The fluidity and multifaceted structure of EU HE cooperation showcases how successful collaboration needs to be structurally nurtured, and enabled via appropriate policy actions. In other words, reconnecting Computer Science Education with the World Out There through policy is an act, to use Callon's terminology, of enrolling the World itself.

We will spend the rest of this Chapter conducting a brief analysis of how the different types of cooperation — in the form of EU HEI consortia — can support different actions in the education space, with a particular focus on CS education and its relationship to Innovation and Entrepreneurship. In many ways, this Chapter represents a subjective mapping of Europe and its landscape of consortia.

4.2 EU HE Consortia

Our main reflection that underlines the link between practices and mindsets can be extended to the domain of EU HEI consortiation. With its complex web of procedures, the many forms of collaboration between HEIs that arise in Europe take different characters based on their structural origin. In other words:

> As the form of an organisation shape its capabilities [152], the origin of a EU HE consortium shape its ambitions, forms of collaboration, and potential for results.

In this section, we want to propose a simple taxonomy of EU HE Consortia, underlining how different classes of consortia are better-suited to attain specific objectives, mapping them with the work we have conducted.

We do this for two reasons: first, to aid the reader in understanding how each context where we operated in affected our approach in pedagogical design and policy ambitions of each intervention; second, to underline how each form of consortiation carries implications — from financial, to administrative, to the ability to exert pressure in an institutional context.

We broadly classify EU HE Consortia in four categories:

1. **Top–down Consortia**: consortia that are explicitly sought by EU institutions through formal documents such as Communications of the European Commission. In this document, we will present EIT Digital as an example of this category.

2. **Policy–driven Consortia**: large-scale consortia that aim to achieve practical results, but also broad policy targets. Usually created to answer a specific call for proposals. In this document, we will present the 2019 Erasmus+ KA3 OpenU Consortium as an example of this category.

3. **Objective–driven Consortia**: these are also consortia created adhoc to answer a specific call, but smaller in size, and often focusing on delivering tangible project results. In this document, we will present the 2017 Erasmus+ KA2 C-Extended Consortium as an example of this category.

4. **Grassroots Consortia**: consortia created from grassroots dialogue and cooperation between institutions, lacking the formal backing of EU funding. In this document, we will present the ECIU Consortium as an example of this category.

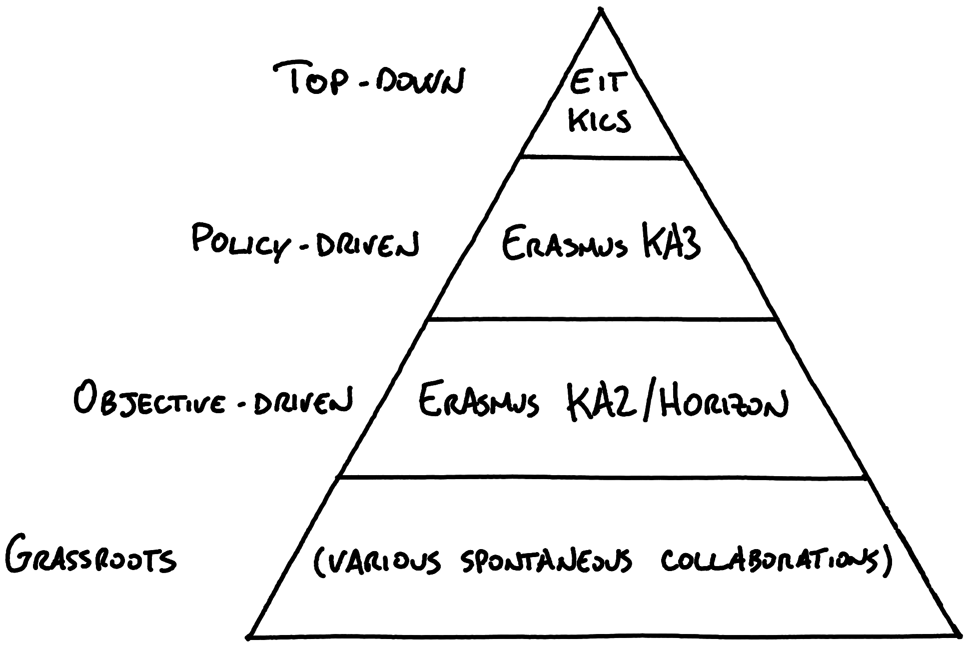

Figure 4.1: Our proposed taxonomy of EU consortia (with examples). Going higher in the pyramid, consortia tend to be more explicitly mapped to policy ambitions, have higher institutional weight, higher funding, and more institutional weight.

This taxonomy holds a number of implications. From the bottom to the top, we can observe a few general features being prominently featured. To name a few, higher-positioned consortia tend to have: 1) more explicit mapping to EU policy; 2) higher administrative overhead; 3) higher reporting overhead; 4) higher funding; 5) more partners; 6) higher weight inside partner institutions.

Furthermore, consortia fluidly move between the levels of our taxonomy: based on individual and collective needs and opportunities, consortia might find themselves moving from grassroots initiatives as far as top-down consortia, or a large top-down consortium might dissolve, only leaving a number of grassroots collaborations as its legacy.

We will now briefly describe each of these categories through an example, to showcase how an archetypical consortium might look like, and give an idea of what are the opportunities and constraints that rise from each of these forms. This exercise should reinforce the argument, widely discussed in the rest of this thesis, that organisational forms, mindsets, and practices are intimately interlinked, enabling or inhibiting certain forms of work and collaboration.

4.2.1 Top–down consortia

As a representative of the most top-down form of consortiation, we propose the Knowledge and Innovation Communities (KICs) of the European Institute of Innovation and Technology (EIT).

The EIT and its KICs first appeared as a policy initiative in 2006, as part of one of the EC's Communications [58]. From that first conceptualisation to their implementation, the form changed a few times. Most notably, a 2009 EC Communication changed the definition of the first KICs. The substance of the EIT and its KICs, however, remain unchanged: the KICs are supposed to connect the three sides of the so-called Knowledge Triangle, namely Education, Research and Innovation [70][71].

The KICs' disciplinary fields originate from broad EU policy areas, often linked to the Framework Programme's Societal Challenges. Each KIC represents an aggregator of European excellence in its field, under a sub-

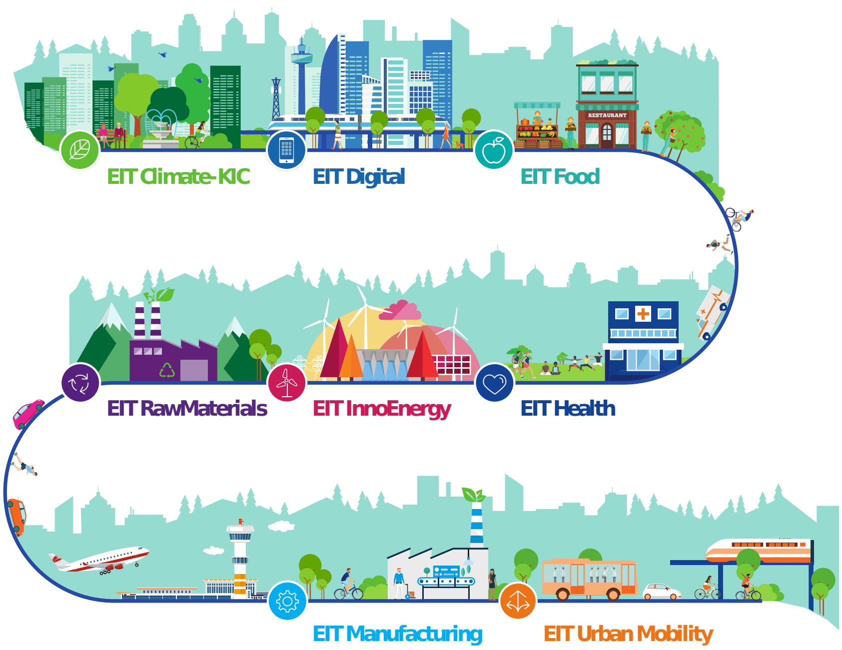

Figure 4.2: The KICs of EIT[1].

stantial academic leadership. EIT KICs nonetheless have their own governance structure: they are a legal entity of their own, separated from the central EIT which is, once again, its own legal entity.

For our purposes, we do not need to analyse the complex and intricate structure of EIT KICs (which are also not homogeneous in their structure): it suffices to say that they are distinguished from other HE consortia because of their explicit framing in EU policy. Partner HEIs have the freedom to define how best to implement their strategy, but their broader policy ambitions are pre-defined, and outside of their control.

In the context of this thesis, EIT KICs have the highly desirable quality of having a strong structural influence on the partner universities, and being able to exert this influence to align partners to their broader policy ambitions. They are also linked to streams of sizeable and long-term funding, making them prime spaces to develop long-term impact. It is no

[1]Source: adaptation from EIT Infographic at https://eit.europa.eu/sites/default/files/2018_eit_infographic_update.pdf.

understatement to say that, without the EIT KICs' top-down nature, much of the work of this thesis in the I&E space would not have been possible.

Most of our interventions have been carried out in the context of the EIT Digital KIC, and in particular within its Master School. The Master School consists of a number of two-year Master's degrees, that each student undertakes in two different universities that are part of the consortium. The most interesting feature of the Master School in our work, however, is that it implements an "I&E Minor Degree" of 30 ECTS, coordinated between all partner universities.

The concept of the coordinated I&E Minor is unique in the world, and attempts to replicate its model in other consortia are still at very early stages.

Even within I&E education in the EIT Digital, partners formed smaller working groups or sub-consortia to work on specific projects to apply to funding that is either from EIT Digital itself, or from other entities. These opportunities can arise only because of the comprehensiveness of the EIT KIC model.

4.2.2 Policy–driven Consortia

Policy–driven consortia are created to support European actions of policy reform, and often include a variety of policy-making actors. Example of this type of consortia are the 2018 Erasmus+ KA3 consortia [74], or the current HEInnovate/EIT "HEI Initiative" consortia [72].

These consortia appear in EU policy only indirectly — they are usually formed to answer a call for proposals with explicit policy ambitions. In the case of the 2018 Erasmus+ KA3, for example, the Programme Guide says that actions in this domain "support [...] policy reform [...], targeted at the achievement of the goals of the European policy agendas, in particular the Europe 2020 Strategy, of the Strategic framework for European cooperation in education and training (ET 2020) and of the European Youth Strategy.".

The link between policy and collaboration is made explicit, requiring each consortium to explicitly frame their work in terms of their policy impact. Interestingly, while the substance remains the same, the most recent version of the Erasmus+ Programme Guide [76] reframed KA3 as "support to policy development and cooperation", and describes its goals more generally as "[actions] that contribut[e] to the development of new policies, which can trigger modernisation and reforms".

The presence of policy-making actors inside these consortia gives these consortia a more concrete pathway to the implementation at local, national, or EU level of the work they carry out. These consortia are, however, "episodic" in nature, with funding attached to individual projects, and thus happening in shorter cycles. This greatly diminishes their ability to exert influence over partner institutions, aiming instead to close the policy-making cycle [106] through a long-term feedback of the actions they pilot.

As an example of this type of consortium, we propose the OpenU project, funded in 2019 as an Erasmus+ KA3 project, and whose structure we schematise below, at Table 4.1.

The structure of consortia such as OpenU tells much about their ambitions and how they plan to achieve their impact: they include sub-groups of top–down consortia, other policy–driven consortia, grassroots collaborations, and state actors.

4.2.3 Objective–driven Consortia

When the EU's policy ambitions need to be transformed into actions, EU HE consortia are formed around concrete objectives — be they based on research or on education. This is the case of what we call Objective–driven Consortia, such as the Erasmus+ KA2 actions [74][76] or, more broadly, research consortia financed under the Framework Programmes.

Cluster	**Organisation**
Policy	German Academic Exchange Service German Ministry of Education Portuguese Ministry of Education Latvian Ministry of Education Spanish Ministry of Education French Ministry of Higher Education Flemish Government International Exchange Erasmus Student Network
Experimentation 1	Université Paris 1 Panthéon-Sorbonne Universidad Complutense de Madrid KU Leuven Università degli Studi di Bologna Freie Universität Berlin
Experimentation 2	Université de Rennes 1 Aalto University Università degli Studi di Trento Universidad Politécnica de Madrid
Implementation	European University Foundation European Association of Distance Teaching Universities
Evaluation	Universität Potsdam

Table 4.1: A visualisation of the partners in the OpenU consortium. Notice the balance between policy actors and academic partners.

In this case, the spillover of project objectives into policy tends to be less explicit, and consortia tend to be the implementers or experimenters of policy rather than its authors. As an example of this, the 2020 Erasmus+ Programme Guide states that "[a]ctions [in] this Key Action are expected to contribute significantly to the priorities of the programme, to bring positive and long-lasting effects on the participating organisations, on the policy systems in which such Actions are framed as well as on the organisations and persons directly or indirectly involved in the organised activities.”.

The smaller scale and lower policy ambition of Objective–driven consortia makes them a suitable tool to develop and deploy in an agile manner those actions that would be too cumbersome to coordinate within consortia that are either larger, or involving more complex organisational and decisional structures.

As a local example of this class of consortium, we propose the consortium that worked on the Erasmus+ KA2 C-Extended project. This itself represents the combination of a subset of a previous consortium that worked on a FP7 project with some EIT Digital partners.

Project Goal/Element	**EU Policy Ambition**
Blended mobility	Micro-credentials
Award of ECTS for online courses	Erasmus virtual mobility
Collection of administrative best practices	Standardisation of EU HE administration
Intersectoral mobility	Strengthening of “knowledge triangle”
Interdisciplinary paths	Lean “minor degrees”

Table 4.2: A mapping between some goals of the C-Extended project and EU policy trends.

The structure of this type of project make it so that there can be a clear mapping between policy trends and piloted actions, as it can be seen in Table 4.2. To go back to the idea of “entrepreneurial Europe”, each of these experiments is a way to test in relative isolation the potential impact and pitfalls of a pathway of policy implementation.

4.2.4 Grassroots consortia

As the least structured form of collaboration, we present here what we call “grassroots” consortia. Much like communities of practice, or other forms of bottom-up communities of professionals, grassroots consortia form when individuals or universities aggregate around common interests, even without formal recognition.

As spontaneous aggregations, grassroots consortia do not appear in policy, and are often (at least in the early stages) not financially supported. Nonetheless, successful grassroot cooperations have the potential to continue for a long time and shift, in subgroups or as ensembles, to the other classes presented above.

As an example of this type of consortium, we propose ECIU, the "European Consortium of Innovative Universities"[2]. Started as a grassroots collaboration aiming to foster deeper connections between participating universities, ECIU has been able to receive funds from many different sources, and consolidate into an entity that has a say in the strategic direction of its partners.

In this way, grassroots consortia can resemble what we have taxonomised as the most structured of collaboration forms: top–down consortia. Indeed, even without a single and stable source of funding, long-standing grassroots collaborations can make use of capacity built over a long stretch of time, participating in the policymaking process as empowered social actors [32].

4.2.5 Project Mapping

To conclude this Section, we want to propose a brief mapping of the activities exposed in this thesis to the consortia and projects they were developed in (Table 4.3).

This mapping serves not only a summary purpose, but also gives an anecdotal example of the taxonomy proposed above: the top-down consortium we worked in was the one that affected our work the most. Other collaborations were built to synergise with EIT Digital, so they hardly took "leading" roles in the activity development.

[2] See `https://www.eciu.org`

Activity	**Intervention area**	**Consortia**
I&E Basics course (Including Technology Battles)	Mainline I&E	EIT Digital, C-Extended
I&E Studies course (Including transition to Blended Learning)	Mainline I&E	EIT Digital, ECIU, OpenU (future)
Master School Kick-Off	I&E Experiences	EIT Digital
DT Summer School	I&E Experiences	EIT Digital
Aveiro entrepreneurship education setup	I&E Experiences	ECIU (and eBridge Alliance)
SDE Course	Technical Education	EIT Digital
Fab Lab	Fab Education	EIT Digital, C-Extended, ECIU

Table 4.3: Mapping between activities reported in this work and what consortium context they have been developed in.

Chapter 5

Conclusions & Future Work

Because of the breadth of the work that was undertaken, drawing a single body of conclusions would not be feasible. We propose here instead some key insights and lessons learned that represent, above everything, avenues for further exploration and future reflection. Our hope is that these can serve both as a closure of our initial explorations and a setting of future work agendas.

The Human: Computing is about the social. Both individual voices [62], as well as collective ones [63] [118] [2] are recognising the need to re-contextualise and better integrate the non-technical dimension of computing, what we have called in this thesis "the Human".

Our experience has confirmed the general impression that most CS students still hold the perception that computing should be purely technical, and show lower interest for non-technical perspectives. Nonetheless, we have also presented a possible way out (see 2.4.2): if we rethink how non-technical subjects are taught in CS curricula, we can help students contextualise and see the Human in CS.

Our experiences in the Pandemic during the second half of 2020 (that are at the moment still being written for publication), however, show that this can hardly happen as a top-down push. Leveraging the pandemic as an amplifier of the challenges that students normally face when approaching the Human component of CS (in our case I&E), our first results suggest that teachers need to understand the students' struggles, and accompany them in the process of learning and unlearning.

Our preliminary work conducted in 2017 (see 2.4.1 and 2.4.3) hinted us that there is an interest for practices and interventions that discuss how teaching methods can facilitate the process of exploring "the Human" in CS. At the same time, this work also allowed us to conceptualise some of the challenges and additional complexities that can arise from the Digital Transformation of education.

In the few years where we conducted this work, some trends changed dramatically: the narrative around I&E (and especially Big Tech companies) moved from having a generally positive outlook to a much more disillusioned one. Critique to so-called "platform capitalism" is no longer a fringe position. As a prime example, data businesses, which at the beginning of our work were hailed as "the new oil" have shown how this metaphor is all too adequate: data harvesting can ethically problematic — even causing substantial carbon emissions [210].

The pandemic exacerbated the building of a general awareness that technology and computing are not and can not be the solution to all contemporary challenges. Even previously "hyped" fields such as cryptocurrencies are now under close scrutiny by regulatory bodies due to their environmental and economical impact. The I&E field, which so far has pushed a narrative of disruption at all costs and "going out there and breaking things" is starting to question this stance, if nothing else, due to a change in market interest. While we cannot yet substantiate this claim with data, we had a feeling that student interest is also starting to shift.

If computing is about the social, we need to investigate computing and its teaching as social phenomena. The lenses we have presented give us some possible tools to do so: our inclusion of ambiguity creates a space where we do not need to wait for consolidated bodies of data before we can start reflecting on our world; ANT gives us a way to disentangle the complexity created by the introduction of technology in the classrooms and suggest where we can act to take (back) control of our educational messages.

This change in perspective leads us to abandoning the sleek objectivity of engineering-based disciplines and enter the messy, subjective space of humanities. Our experiences suggest that what we have described as our Goal (see 1.1.3) is, indeed, attainable, if we accompany this shift in discipline with a comparable shift in modes of inquiry. Possible such directions go towards the many methods for qualitative research developed by social science, as these research methods have the added benefit of reducing by design the potential for reification of the actors involved in the education and research process. In other words, if we wish computing to reconnect with the social we need — at the very least — to welcome once again Human presence in the picture at all levels.

The Machine: Computing is alive. Our reflections on technology obsolescence — and how to teach in a CS landscape that is obsolescing ever more quickly — gave us a possible way out of the deadlock generated by the interaction between technological evolution and its teaching: leveraging students' latent knowledge.

Both in the case of curricular and extracurricular activities, we have experimented how we can use some of the insights and modalities that we first encountered in I&E education — chiefly, mentoring — to combine the lecturers' long-term experience with the students' interest in the latest technologies.

The main benefit of this process is that students and teachers can team up to create a learning experience that can match the well-established paradigm of teaching "evergreen" technical concepts with the need (also present in the jobs market) for universities to make students experience "hot" technologies.

Such a change in perspective frames the Machine as something that constantly changes, carrying with it a host of ever-shifting designers' intents. In some ways, this represents another way to frame computing as a social phenomenon: learning becomes entangled with human relationships and social dynamics between students, their teachers, and their peers.

Unlike in "the Human", there is no interest gap to bridge in this context: CS students are highly motivated to seek the latest technologies and learn more about them. The expertise and longer-term perspective of teachers, however, can guard students against the oft-encountered problem of excessive attachment to technical novelty.

This approach of teaching technical subjects through mentoring and channelling of latent knowledge not only mirrors practices encountered in the workplace such as pair programming, but also enables direct collaboration between students to fill each others' knowledge gaps, even creating on-the-fly opportunities to address curricular gaps.

If computing is alive, we need to be ready to adapt quickly our object- and meta- level knowledge about its technical practice. This puts into discussion the role of the teacher as the main holder of knowledge, and brings it towards a mentoring/facilitator role — something that we also encounter in non-technical education. Once again, we see our results as extremely preliminary, but we find it fascinating that it is exactly the technical domain that showcases a clear pipeline for the inclusion of social dynamics in the CS education space.

The World: Computing (education) is for all. As the last bit of conclusions — but also as limitations and leading towards our discussion of future work — we want to address a key dimension that has been gaining relevance in the latest years' policy and public discourse: diversity.

With all of our discussion of the subjective and importance of context in education, computing faces the extra challenge of being a discipline that greatly benefits from a relatively wealthy environment. From access to energy, to internet access, to buying power to acquire computing resources, computing has so far been strongly tied to the Western world.

Examples of the impacts are tangible: algorithms show racial biases [122] [155]; technologies encode gender discrimination through their interfaces[1]; access to online education is tied to wealth [187]. These and countless more examples show the urgency of addressing the diversity dimension in computing.

Work conducted in this thesis, sadly, also suffers from these biases: our classes were taught in a wealthy region of a wealthy country, to an overwhelmingly male audience. We cannot have the pretense of having worldwide generalisable results, as we also discussed in the introduction (see 1.2.4), but our efforts are also oriented towards the achievement of more diverse and inclusive education.

Our emphasis on pedagogy, with our attempts to educate to a critical use of technology, is part of this effort, as is our attempt to reframe entrepreneurship as a social endeavour, and our emphasis on ethics of technology. These challenges and limitations are not only of moral or political nature, but also represent a research ambition.

Our future work aims to continue the reflections presented here, by looking at this ambition in two dimensions: 1) a methodological dimension,

[1] See for example an informal discussion of airport scanners at `https://edition.cnn.com/travel/article/tsa-body-scanners-transgender-travelers/index.html`

with the goal of developing relevant assessment methodologies to extract insights from our actions; 2) a sustainability dimension, with the ambition to contribute to the process of DT of education by exploring a critical use of EdTech.

Methodology: Observing the subjective. If a key aspiration of science is that of facing so-called "wicked problems" [179], that are ill-defined, education has plenty of science ahead of it.

As we discussed in 2.2.1, the field not only has to deal with the conundrums that are found in any other discipline, it has the additional burden of an ill-defined and subjective measurement process. Measurement itself is a wicked problem!

Education ends up being in a unique position. Some disciplines such as pharmaceutics or medicine see the wide-reaching deployment of a product (e.g., a drug) *after* its effectiveness has been proven by research. In education, by contrast, constructivist education methods have been theorised more than 100 years ago, and quickly moved into practice; researchers have been calling constructivist pedagogies "dominant" as far back as 15 years ago [97], but the debate around them is still very open.

As a compounding problem, we can look once again at knowledge obsolescence: what is taught in a university today shapes the mind of professionals that will remain in the (European) workforce for around 45 years [156]. As of the time of writing, the Apple II, recognised as one of the first personal computers, is but 44 years old.

If the object of our teaching obsolesces, our teaching methods might be disproved in the future, and we have no way of stably measuring the effectiveness of our interventions, what should we reasonably do?

The safest answer would be to stick to time-tested practices (i.e., lecturing), and quit our endeavours altogether. But even if those practices survived the test of time so far, are we sure they will keep surviving it, or are we building for ourselves a fallacious induction?

Methodologically, our future work orientation goes in the direction of analysing and exploring methods of classroom observation (such as those presented by O'Leary [158]), with the goal of creating a body of mixed assessment methods that can combine quantitative insights to extensive qualitative observations.

As much as we have discussed that CS can reap great benefits from abandoning an "uncertain" view of the discipline to embrace an "ambiguous" view of it, we would like to see if there is space for computing education to embrace the subjectivity of the education process while retaining the ability to generate generalisable research insight.

Sustainability: towards educating in and for a new computing. Why do we keep educating for a "Simonian", uncertain, view of computing when our world is so ambiguous? The change management process during these times of accelerating DT of education is complicated. While computing paradigms change, they also change our world at an accelerating speed and, with the effects of the pandemic, we are now seeing unprecedented impacts of technologies in the education space.

The process is, however (and thankfully!), far from complete. There is still low awareness about how these technologies born from an ambiguous world bring ambiguity inside the classroom, and questions about how the DT of education interacts with our broader global context are being raised only recently, for example by Selwyn [189] [187].

A particularly relevant dimension in this sense is that of the *sustainability* of EdTech: our ANT lens reminds us that choices surrounding EdTech are not only technological in nature, but also carry with them the intents of their designers. As a consequence, the impacts of EdTech are also pedagogical (what kinds of classroom dynamics they enable/inhibit), social (does a technology include or exclude some demographics), legal (what are the privacy implications of using a technology over another), environmental (what are the impacts of adopting certain technological stacks), and more.

There is ample research opportunity to foster a critical dimension of EdTech before the system reaches a stable *status quo* and we close the debate around the DT of education. Part of our future work will pursue this direction, and analyse the interaction between pedagogy and technologies.

The increasing attention surrounding the climate crisis and phenomena of global over-exploitation implies that we need not only to face the question of how to make our education systems resilient, but also sustainable, triggering a deep reflection of what is the legacy of our education. Never as in this context, we see the word "sustainable" beyond its meaning as a policy buzzword, and rather as having complex implications along all the 17 Sustainable Development Goals of the United Nations.

Within limits; with new horizons The last years have shown to us with increasing insistence that "the World out there" has clear limits, and so should have human activities. Computing should be no exception [150]. Beyond sustainability and a de-growth perspective, we want to go back to our idea of "constrained creativity" (see 2.2.2).

Constraints and limits fuel creativity: even if our first instinct is to see a potential end of growth as a threat, we should also ask ourselves what areas of human knowledge might experience a new resurgence in this new environment. STEM disciplines have for a long time been able to ride the wave of exponential growth, often proceeding at such a speed that new generations of advancements rise before the current ones are fully explored. We need to look no further than to our controversial relationship with e-waste to find a tangible example of this dynamics.

Our call to go towards reconnecting CS education with the World out there is exactly in this direction. Rather than succumbing to a fatalistic view, we prefer to raise a last question: as machines start treading our planet, how can we make sure that they help us nurture it, rather than exploit it?

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