SFUVET

EPFL

Pierre Dillenbourg · Alberto Cattaneo · Jean-Luc Gurtner · Richard Lee Davis
Editors

Educational Technologies for Vocational Training

Experiences as Digital Clay

SFUVET

SWISS FEDERAL UNIVERSITY
FOR VOCATIONAL EDUCATION
AND TRAINING

Swiss excellence in vocational education and training

EPFL

UNI
FR

UNIVERSITÉ DE FRIBOURG
UNIVERSITÄT FREIBURG

Editors
Pierre Dillenbourg,
EPFL, Lausanne

Alberto Cattaneo,
SFUVET, Lugano

Jean-Luc Gurtner,
University of Fribourg, Fribourg

Richard Lee Davis,
EPFL, Lausanne

Publishers
SFUVET
EPFL

Cover
Adobe Stock

Acknowledgements
This book presents the results of research conducted in the context of the "Dual-T – Technologies for vocational education" project, funded by the State Secretariat for Education, Research and Innovation SERI.
It does not necessarily represent the opinion of the SERI, and the SERI is not responsible for any use that might be made of its content.

ISBN
9798354160044

Educational Technologies for Vocational Training

Experiences as Digital Clay

Pierre Dillenbourg · Alberto Cattaneo · Jean-Luc Gurtner · Richard Lee Davis
Editors

Index

Introduction 2
Pierre Dillenbourg, Alberto Cattaneo, Jean-Luc Gurtner, Richard Lee Davis

Chapter 1
The Swiss VET system 8
Pierre Dillenbourg

Chapter 2
Learning technologies as a powerful way to turn alternation into an opportunity to embed theoretical knowledge in practical experience: The Erfahrraum model 16
Alberto Cattaneo, Jean-Luc Gurtner

Chapter 3
Collecting and saving meaningful experience: The bakers' and chefs' stories 21
Alberto Cattaneo, Jean-Luc Gurtner, Elisa Motta, Laetitia Mauroux

Chapter 4
Sharing experience: The painters' story 32
Jean-Luc Gurtner, Alberto Cattaneo, Alessia Coppi

Chapter 5
Annotating experience: The clothing designers' story and beyond 42
Alberto Cattaneo, Jean-Luc Gurtner, Valentina Caruso, Alessia Coppi

Chapter 6
Manipulating experience: The Logisticians story 52
Pierre Dillenbourg, Patrick Jermann, Guillaume Zufferey

Chapter 7
Augmenting experience:
The carpenters' story 64
Pierre Dillenbourg, Sébastien Cuendet, Lorenzo Lucignano
and Jessica Dehler-Zufferey

Chapter 8
Expanding experience:
The gardeners' story 77
Pierre Dillenbourg, Kevin Gonyop Kim

Chapter 9
VET analytics 89
Richard Lee Davis, Son Do-Lenh, Mina Shirvani Boroujeni, Ramtin Yazdanian

Chapter 10
Synthesis 100
Pierre Dillenbourg, Alberto Cattaneo, Jean-Luc Gurtner, Richard Lee Davis

Epilogue 102
Friedrich Hesse, Etienne Wenger-Trayner, Jim Pellegrino, Mike Sharples,
Ulrich Hoppe and P. Robert-Jan Simons

References 111

Introduction

Pierre Dillenbourg, Alberto Cattaneo, Jean-Luc Gurtner, Richard Lee Davis

The last time you went to the bakery, did you wonder how the baker had been trained? Did he follow theoretical courses or only practical ones? What about your car mechanic? Do you know how long her training was or whether it was generic or specific to a car brand? How long did her training take and was she being paid during this time?

Similar to most people, you may not be able to fully answer these questions. As a matter of fact, these answers vary country by country, often according to profession. In Switzerland, where vocational education and training (VET) plays a central role in the educational landscape, citizens might be able to provide some answers. They would tell you that VET is applicable to two-thirds of Swiss teenagers, that it is taught during the upper secondary school (± 16-20 years old) and that it covers many professions (salespersons, carpenters, hairdressers, office clerks). Indeed, over 240 professions come under VET training. They might also explain that the Swiss VET system is described as 'dual' because most apprentices alternate one or two days per week at school with working in a company as employees and receiving a salary.

These are easy questions, but for many years, higher-level questions have remained unaddressed by local universities. Is the Swiss VET system actually effective? Do host company trainers provide high-quality follow-up for their apprentices? Is school content relevant to the workplace? Do apprentices constitute a cost or a benefit for companies? Are there dropouts and what are the causes for them dropping out? For decades, Swiss universities have seen many scholars investigating other sectors of education, from kindergarten to lifelong learning, but only a few universities researched VET. Realising this weakness at the beginning of this century, the State Secretariat for Education, Research and Innovation (SERI), that is, the federal office in charge of VET, invited various consortia to apply for funds to do research according to several themes. One of these themes was about the development of digital technologies in VET contexts, and we obtained this research grant as a partnership between four institutions (see acknowledgements section).

This book summarises 15 years of research (2007-2021) on the exploitation of digital technologies for VET. In other words, our activities started the same year as the first iPhone was launched! Four research groups formed the leading house on the topic, named DUAL-T, where T stands for technologies and DUAL refers to the Swiss VET system, relying to a great extent upon the alternating of days at school and days in the workplace. This uniquely long-term research scheme has gathered more than 50 research scientists, produced 13 doctoral theses, led to the development of multiple digital learning environments and enabled dozens of empirical studies on thousands of apprentices and hundreds of teachers and company trainers. DUAL-T developed a network of stakeholders, including vocational schools and companies, but also many professional organisations and cantonal or national public entities. This book does not provide a detailed account of all these activities, which have been published elsewhere. But it proposes several answers to the question:

"***Which digital technologies contribute to the enhancement of vocational education?"***

In VET systems, as well as in other education sectors, the choice of educational platforms is not made by teachers but is often a decision taken at the school, the district or a higher hierarchical level. Therefore, along our 15 years of negotiations with schools, many teachers declined to use one of our tools because they were constrained by these top-down decisions. In this book, we aimed to make design choices as independent as they could possibly be from school platforms. Some constraints could not be avoided, but some ideas that used our tools could be implemented with WhatsApp, Instagram, MS Teams and Google Drive.

Target audience

The VET systems around the world are different from the Swiss VET system, with the exception of Austria and Germany, and, partly so, the Netherlands. However, we paid special attention to describing our work in a way that would be meaningful beyond Swiss borders. We wrote this book because we believe that many of the issues we tackled are relevant for any VET system worldwide, such as the differences between knowledge taught at school and knowledge required by the profession. Moreover, we think that many of the solutions we tested and more generally the pedagogical approach we developed could be useful even beyond VET, that is, wherever formal and informal learning occasions happen, which happens almost everywhere in one's professional life.

We also wrote this book as an invitation to the international community in the learning sciences and in educational technologies to pay more attention to the VET system in their own country, even if it is differently structured. As many researchers in university labs have not gone through a VET path, the VET context is clearly under-sampled in academic publications. We would even add that several of the issues we address are relevant beyond VET: tangible manipulations, augmented reality or learning analytics are affordances that enhance any sector of education. Therefore, we expect this book to generate ideas for many education scientists, whatever domains and countries are involved in their studies.

Potential effects

What are the effects of massive open online courses (MOOC) on education? That is the kind of wicked question we have been often asked in recent years. The only rigorous answer should be 'none', or, to be more verbose, it could be that good MOOCs are better than bad MOOCs. This 'Lapalissade' applies to any variation of this question that you obtain by replacing MOOCs with other terms, such as augmented reality, artificial intelligence and robotics. The history of learning technologies is paved with over-generalisations and their corollary, over-expectations. They result from a mix of enthusiasm and naivety, or commercial interests. Over-expectations are actually detrimental to education, since they inevitably lead to disappointment.

We conducted many empirical studies with the digital environments we describe in this book, some with disappointing results, some revealing statistically significant increases in learning gains. However, even in the successful cases, we carefully do not conclude that technology X has effect Y, for instance, that tangible interfaces increase learning outcomes. Over-generalisations generate over-expectations. An experiment with successful outcomes does not guarantee that any tool using the same technology will produce the same results. **These experiments demonstrate a potential effect, not a guaranteed effect**. As an example, even if a study showed that some augmented reality (AR) environment increased learning gains, one cannot extrapolate that any AR would have the same effectiveness in any context. It would, of course, be easy to design another AR in which learners fail to acquire any knowledge. Does this mean that we cannot conclude anything from a successful experiment? Of course not! What is important to stress here is that technology has no direct, automatic effect on learning, as the relationship between technology choices and learning outcomes is a multi-step one. This relationship comprises four steps: (1) when incorporated into the training appropriately (from an instructional design point of view) by teachers and trainers, the technology enables learners to (2) engage in specific individual or team activities (e.g. problem solving, reading, arguing, explaining) and these activities (3) trigger cognitive processes that (4) occur to influence the learners' skills or knowledge. For instance, one may obtain great results (4) with an AR system (1) for gardeners and poor results (4) with another AR system on the same skills because the activities (2) that apprentices do in the latter do not trigger the required cognitive processes as they did in the former example. The goal of this book is to reveal this causal chain. The following chapters disentangle the design features of a technology (1) that enables rich VET activities (2) that are in turn hypothesised to trigger cognitive processes (3) that support learning (4). We will even see that there is a fifth factor in the equation: the way the teacher orchestrates these activities in the classroom.

Research questions and structure of this book

We first provide the reader with background information about the Swiss VET system. **Chapter 1** is not a comprehensive overview of this system but provides the contextual elements necessary not only to understand our research activities, but also to disentangle from the contributions of this book the ones which can be exported to different VET or non-VET systems.

We now present an outline of the other chapters in chronological order.

We started with a simple question: ***can VET use the same learning technologies as other upper secondary schools?*** The answer is rather positive for learning technologies that do not include any initial content, such as learning management systems, classroom participation systems or collaboration tools, the contents being added by teachers and learners. Many VET institutions use the same generic tools as other schools: Moodle, Zoom, Google Drive, clickers, for example. The answer to the main question is different for tools that embed specific content, such as online courses or science simulations. In fact, VET curricula include a subset of what is taught in high schools in mathematics, languages and citizenship, among other topics, under the umbrella of 'general culture' - also known as 'Language, Culture and Society (LCS)'. However, this knowledge is often addressed by VET teachers in more concrete, less academic ways than in general secondary schools, as the latter prepares students for universities. For instance, a chemistry simulation or a MOOC on mathematical functions that are useful for general high school may be too theoretical for VET students. The true spirit of our overarching research question does not concern so much the reuse of generic learning tools used in high schools as the exploring of technologies that are different from general technologies, that is, that would be specifically relevant to VET contexts. To reflect this bias, our question can be rephrased as: **would a VET system benefit from specific learning technologies, designed purposely for addressing VET needs?**

Even if the presentation we give of the VET system does not cover its full complexity, the reader will immediately understand what German colleagues call the 'two places problem', that is, the misalignment between the two legs of the dual system, the school and the workplace. By talking to teachers, apprentices and company trainers, we quickly realised that 'skills gaps' exist between these two places: what apprentices learn at school is not necessarily perceived by apprentices as useful for their workplace activities and what they do in the workplace does not allow them to give meaning to what is taught at school. These two places differ according to the type of knowledge and skills they provide but also according to their objectives. While workplace managers expect reasonable short-term productivity, schools have a longer-term vision. For instance, when assigning tasks to logistics assistants, warehouse managers do not expect them to reorganise a warehouse – the role of the manager – but simply to operate efficiently based on the instructions given by their in-company trainers. On the other hand, schools teach how storage areas can be optimised, a skill apprentices might benefit from maybe 10 years into their profession once they, in turn, become warehouse managers. In other words, even if skills are impervious to being transferred, that is, reusing in daily work what has been learned at school, they are not a bug in the system, but an intrinsic feature of it: the two institutions, the school and the company, have complementary roles, sometimes having a long- versus a short-term impact. To phrase it differently, a system would not be dual if learners were to encounter identical experiences at schools and in companies. Therefore, the solution to the 'two places problem' is not to eliminate this skills gap, that is, to erase the differences between the school and workplace learning if this was even feasible. Instead, our approach is to exploit these differences by connecting workplace experience and school activities, **to use technologies to let apprentices make sense of what they have learned in one context within another context**. We refer to this first hypothesis as **building digital bridges** between schools and workplaces. We translate this principle into action by capturing experience in the workplace as a digital substance in order to feed classroom activities and, conversely, to enhance workplace activities with transferable school knowledge. We refer to this vision as **'der Erfahrraum'** and develop it as a theme in **Chapter 2**.

Chapters 3, **4** and **5** illustrate **how this vision has inspired teachers and trainers in five rather different professions**, – bakers and cooks (Chapter 3), painters (Chapter 4), and clothing designers and beauticians (Chapter 5) – and how they have managed to take advantage of the technologies we brought them to improve the alignment of these various learning places – bridging the learning advanced at school in line with experiences learnt in the workplace.

Apprentices have to learn skills that are different from what other teenagers have to acquire in high school. VET curricula include profession-specific courses, such as hair structure for hairdressers or wood typology for carpenters. The diversity of these courses reflects the diversity of the 240 professions in the Swiss VET system. Many learning activities in these curricula share the need to manipulate physical objects or to perform professional actions, which is rarely the case in general high school. VET schools also benefit from digital technologies in which apprentices have the opportunity to manipulate, physically or at least virtually, realistic professional objects. When we started in 2006, the interactions between a learner and a learning environment were limited to a mouse and a keyboard, at least in daily practice. To enrich learning with more physical interactions, we pioneered the development of tangible interfaces, but also AR and even virtual reality systems. Nowadays, with the growth of the Internet of Things and the ubiquity of additive manufacturing, the continuity between digital and physical aspects does not need to be demonstrated anymore to the actors of the VET system. **Chapters 6 through 8** describe **how such technologies have been designed and implemented in VET schools** and we report on the results from empirical studies conducted within four different professions – logisticians (Chapter 6), carpenters (Chapter 7), florists and gardeners (Chapter 8).

The more complex a system is, the more effort is needed to monitor the way it functions. Nowadays, a car or a plane are complex systems that are fully monitored through sensors. Some sensors capture data from their inner components; others capture data from the outside environment. Education systems are also equipped with inner sensors, such as failure rates, and outer sensors, such as those that track the professional development of those who have completed the studies. These sensors are rather slow data collection processes, such as surveys or aggregation of school statistics. Therefore, regulatory cycles are several years long. Our third hypothesis is that faster regulation could be achieved by accelerating the adoption of learning analytics. Learning analytics are methods of following the state of learners at different levels of granularity, from the individual performance in a single exercise to the national drop-out rate in some training fields. By collecting data systematically and rapidly, and by processing these data with machine learning methods, technologies provide teachers and decision-makers with faster information. For instance, some machine learning methods, when fed with sufficiently large datasets, might be able to predict whether an apprentice will drop out or not. Several projects within DUAL-T have explored the specific benefits of **learning analytics** for the VET system, as described in **Chapter 9**.

Various technologies rather than a specific technology

This book is not about a specific digital technology. The many meetings we had with apprentices, teachers and in-company trainers, as well as our commitment to work from and around their educational needs, as inferred from these discussions, led us to consider various technological choices and possible solutions.

Our point is that the relevance of other technologies, such as online courses, drill & practice courseware, simulations and intelligent tutoring systems, should not be minimised. Our technological choices result from our quest for VET-specific technologies. One drawback of this approach is that many of the tools we developed are specific to one or a few professions: for instance, our AR tool for an intuitive understanding of statics was designed for carpenters; it is relevant to other construction trades (bricklayers, metallic construction, cabinet makers) but not to salespersons, nurses' assistants or chefs. The didactical ideas behind these specific tools, however, may well be suitable for many more professions. The framework created specifically to teach security and environment protection to painters can easily be transported, *mutatis mutandis*, to the many professions concerned with these issues, such as electricians, chemistry labs assistants, electroplaters, crosscut saw operators and body builders, to name just a few.

What this book does not address

Over the last six years, before the pandemic was heard of, we witnessed a rapid evolution in the attitude of education stakeholders towards the digital transformation of the VET system. The main reason of this evolution is unfortunately not the work that is reported in this book but the digital transformation of professions themselves: the fourth industrial revolution is impacting almost all professions: additive manufacturing, the Internet of Things, systems analytics, on-demand production, online markets. Nowadays, a car mechanic still requires the skills to assemble mechanical pieces, but also needs an understanding of the sensors and digital diagnosis tools that equip all cars. The Swiss VET system is designed to rapidly adapt to the evolution of trades; monitoring those changes is part of its DNA. Few education stakeholders actually distinguish this transformation of trades from the evolution of learning technologies, a confusion that actually helped us get the attention of many stakeholders. However, this book does not address the first topic, only the second. The analysis of job evolution belongs to other fields, distinct from ours, namely economics and sociology, even though we touched on it when applying machine learning methods for predicting the emergence of new training needs (see Chapter 9). Even if they are distinct, these two facets strengthen each other by raising awareness about how VET institutions should accelerate their adaptation to the digital revolution.

The word revolution, used in the previous paragraph, is indeed relevant if we talk about the fast transformation of jobs, but it does apply to the transformation of schools too. Journalists often ask us to predict the next big revolution in education. ‘Are you going to replace teachers with robots?’ is not an uncommon (but a stupid) question. ‘How will education look like in 2050?’ is another common question, which cannot be replied to in any serious way. Yes, there are deep irreversible changes in the education system. Think about Wikipedia or that an apprentice can find several videos on YouTube explaining almost any concept or technique. There are meaningful trends, mainly cultural evolutions, but do not expect a deep education revolution in the next few decades. **This book is not about predicting a future**, neither dramatic nor glorious. It is about informing all stakeholders about **what can be done today** with existing technologies. The future is not yet written: it depends on how teachers, company managers and apprentices will translate digital opportunities into learning successes.

Is this book relevant for those involved in **corporate training**? We will let you judge, as the answer is subtle. The obvious difference between vocational education and corporate training is that the first one is about the initial phase of training and the latter ties in with a professional career. Apprentices have to go to the former, employees usually choose to go to the latter. The former lasts three or four years, the latter a couple of days per year. A noticeable difference is the future of trainees. In vocational education, the company makes no promise to hire the apprentice at the end. Some companies even hire apprentices while explicitly knowing they do not intend to hire new employees. On the other hand, corporate training is offered to employees who are expected to remain in the company; several training managers told us of their concerns that a well-trained employee might leave the company.

Despite these differences, corporate training and vocational education face a common challenge: how is the knowledge acquired during learning/training activities actually used in a way that increases the employee’s performance or job satisfaction? This is an issue for many apprentices, who complain that school is useless, as well as for employees who, when asked to assess the relevance of a seminar, comment more often on the quality of the coffee than about the relevance of the course content. We have never met a chief learning officer or head of human resources who computed the return on investment in his staff training: for every dollar spent on training, how many dollars were gained in higher productivity, better sales, reduced waste, increased customer satisfaction, or staff members' satisfaction at work or their retention? How do education and training efforts actually impact professional practices is an issue both in VET and in corporate training, but it receives more attention in VET. Therefore, this book may also inspire those in charge of corporate training.

Acknowledgements

The following researchers were involved in this research journey:

At the Swiss Federal Institute of Technology, Lausanne (EPFL): Pierre Dillenbourg, Patrick Jermann, Jessica Dehler-Zufferey, Beat Schwendimann, Katerina Oertle, Richard Lee Davis, Guillaume Zufferey, Son Do-Lenh, Sebastien Zufferey, Lorenzo Lucignagno, Mina Bouroujani, Kevin Gonyiop Kim, Ramtin Yazdanian, Manfred Kunzle, Emily Lettry and Florence Colomb, as well as many master students and summer interns.

At the Swiss Federal University for Vocational Education & Training (SFUVET): Alberto Cattaneo, Christoph Arn, Elena Boldrini, Valentina Caruso, Alessia Coppi, Martin Dobricki, Gianni Ghisla, Elisa Motta, Markus Sanz and Berno Stoffel, as well as many teachers and teacher students who helped us implement our field experiments.

At the University of Fribourg: Jean-Luc Gurtner, Joris Felder, Nicole Furlan, Laetitia Mauroux, François Jimenez and Jessica Dehler-Zufferey.

At the University of Geneva (during the first half of the leading house): Mireille Betrancourt, Daniel Schneider, Monica Gavota and Giulia Ortoleva.

The leading house was coordinated by Pierre Dillenbourg, with the collaboration of Alberto Cattaneo and Jean-Luc Gurtner. We benefited from a great advisory board, which met the team annually: Friedrich Hesse, Etienne Wenger-Trayner, Jim Pellegrino, Mike Sharples, Ulrich Hoppe and P. Robert-Jan Simons. The research programme was supervised by a research committee successively led by Fritz Oser, Frank Achentagen and Christiane Spiel. We received great support from these experts, as well as from the State Secretariat for Education, Research and Innovation (SBFI), namely Josef Widmer, Serge Imboden, Johannes Mure and Isabelle Schenker.

Chapter 1

The Swiss VET system

Pierre Dillenbourg

If you watch a crab walking on the soft sand of a beach, you will consider the 3D movements of its legs as extremely complex. They are. However, this complexity comes from the complexity of the sand micro-landscape, which, at the crab scale, is made up of myriad irregular hills and valleys. This chapter will reveal that the Swiss VET system is way more complex than the adjective 'dual' may convey. As it is for crabs, this complexity comes from its adaptation to the underlying Swiss economic landscape and its political culture. Understanding how an education system fits its societal ecosystem is a condition for exporting some of the ideas presented in this book to other VET and non-VET contexts.

This chapter starts with a bird's-eye view of the Swiss VET system, zooms into its complexity and relates it to its ecosystem. There are many studies on the Swiss VET that go much deeper than this chapter. We do not aim to give a complete picture but to point to some elements worth noticing. Readers who are familiar with the Swiss VET system may, of course, skip this chapter or enjoy an original and subjective viewpoint, since three of the four editors of this book were not educated in Switzerland.

The glossy picture

What do Guy Parmelin, the president of the Swiss Confederation (at time of writing), Sergio Ermotti, recent CEO of UBS (one of the largest banks in the world) and Claude Nobs (founder of the Montreux Jazz Festival) have in common? We have heard many Swiss speakers asking this question, which discloses a justified pride in the Swiss VET system. The answer is that the three of them started their career with an apprenticeship. If you ask the same question about French leaders, the answer would be a 'grande école', such as SciencesPo, ENA or the Ecole Polytechnique. The Swiss official discourse places VET somewhere close to Roger Federer. One can argue whether this is exaggerated, whether field practices are as glossy as the postcard presented to the many foreign VET delegations visiting the country. The system is often praised as one of the factors that explain the low unemployment rate and the health of the small and medium-sized enterprises (SMEs) sector, which constitutes the core of the Swiss economy. This relation is discussed at length by economists. However, whether the picture is embellished or not reveals a peculiar sociological fact: do you know of any other country that is so proud of its VET system? Our federal authorities are eager to maintain this reputation of excellence, which they consider an asset for Swiss companies competing in the international market. Their willingness to develop our leading house on learning technologies reflects this continuous quest for excellence.

VET plays indeed a central role within the overall education system. After compulsory education, at around 16 years of age, students choose between two tracks for upper secondary schools : the professional track, doing an apprenticeship for three or four years, or the academic track, at the end of which they obtain the diploma (called a 'maturity') required to enter university. In summer 2020, 62% of the upper secondary school diplomas were delivered to apprentices on the professional track. This ratio between VET and general education varies across cantons, VET being more popular in the German-speaking part of the country, but it is indeed one of the highest in the world.

The choice that teenagers have to make is not totally free. Beyond the usual forms of social determinism, two conditions interfere with it. First, pupils need to perform well in elementary and lower secondary school to have access to the academic track. In some cantons, the selection process starts for kids as soon as they are ten years old. Second, entering into an apprenticeship requires getting a contract with an employer. It is very symbolic of the VET culture: in many cases, an apprentice has to sign a contract with a company before being accepted by a professional school. Since

VET is a Swiss tradition, the offer of apprenticeship contracts is globally greater than the demand, but there are demand-offer discrepancies (in one direction or the other) in some professions that cantonal authorities try to manage. Some teenagers do not get a contract because of previous low school performance, behavioural problems or linguistic difficulties.

The end of compulsory school and the beginning of VET is supposed to occur at around 16. Importantly for us, journalists would describe these apprentices as 'digital natives'. It is true that when we tested innovative tools in their classroom, the first reaction was to reach their pocket while asking '*can I take a picture?*' As a school director, Michel Tatti told us that during a graduation cermony '*they arrive as kids and leave as adults; we accompany them in this major phase of life*' (our translation). While the mean age for getting a contract is around 18, some students first start another track and some bosses prefer slightly more mature students. Cantonal authorities offer various transitory structures to handle this uncertain phase of teenagerhood. The success rate is high: 92% of apprentices obtain a professional certificate (Rapport Suisse sur l'Education, 2018). Among those who lost their contract, 84% did another apprenticeship and 90% completed it successfully. Beyond the standard certificate, about 50% successfully pass the exam for 'professional maturity', which enables them to proceed to a university of applied sciences (Rapport Suisse sur l'Education, 2018).

The distribution of professions is skewed. Even though plumbers, carpenters and bakers are often seen as prototypical professions in VET, 24% are office clerks (bank, insurance or public services), 14% are in sales, 9% are in various constructions jobs and 9% are in health jobs. The remaining 44% taper off in a long tail, ending with professions such as blacksmiths, acousticians and woodwind instrument makers. The professions where we experimented with our approaches are not among the most represented ones: sales and office employees. We worked mostly with professions where experience was marked by the production of some artefact, such as a roof, a cake, a bouquet, a garden or a dress. The learning technologies we developed reflect this bias, itself grounded in our research questions. This bias is an explicit choice but also a limitation of our work.

Apprentices' monthly salary starts at around 700 Swiss francs and increases slowly with the years. This is about 11% of the average adult salary here but, nonetheless, it is significant as a starting-off salary. They have to balance this salary with the fact that they will go from the standard 13 weeks of annual school holidays to the mere 5 weeks' holidays for Swiss employees. Economists have shown that the earlier low productivity of apprentices is compensated by their higher productivity in the last year, which leads to a profit for the companies concerned (Strupler Leiser & Wolter, 2013).

Modes of alternation

The Swiss VET system's main characteristic is alternation, that is, a succession of periods at school and periods within a company. The mode of alternation defines the frequency of schoolwork transitions.

In fact, **various modes of alternation** co-exist, with the weekly alternation being by far the most frequent mode to be seen across the country and professions. It is important to delve deeply into its complexity because it actually results from adaptation to diverse contexts, similar to the crab walking on the sand. This local adaptation aims to fit the output of the VET system to the needs of companies. The technological questions we address have to take into account this diversity of modes.

- **Weekly alternation** is the prototypical form of school-workplace alternation in the Swiss VET curricula. It often means one day at school and four days in the workplace each week, but it can also be two and three for some professions and diplomas or in some cantons. For some curricula, it can be 2+3 in the first year and 1+4 in the following years or vice versa. In VET schools, apprentices attend both general classes (maths, languages, accounting), as well as professional theory classes, for example, the wood properties or basic statics for carpenters. As many apprentices told us, they do not expect much from their day(s) at school besides them being less stressful than a normal day in the workplace, where they have to wake up earlier and match the workplace production rhythm. Many of them did not have very positive experiences at school in the past. One interesting function of the school day is to broaden their knowledge of the field by sharing their experiences with peers. For instance, one carpenter apprentice might work in a company that only makes chalets while another could be in a company that makes modern houses. Gathering together at school somehow compensates for the randomness of getting a contract with any one company. We came upon, for instance, some dental assistants who were only cleaning dental instruments all day long, and who benefited from school interactions with other apprentices who were lucky to perform richer activities, such as placing instruments in the patient's mouth.

- **Semester alternation**, that is, something closer to the traditional internship format, in which students register with a school and have to do one or two semester-long internships in a company, also exists in Swiss VET. We found this model in the full-time schools or 'écoles des métiers' as they are called in the western part of Switzerland, where the apprenticeship system does not have the same tradition as in the east. Beyond this historical reason, there are also more practical reasons; in some professions, for instance in IT, an apprentice needs some basic training before being minimally interesting to a company, while in other professions, a fresh novice can already do useful tasks, such as cleaning spaces and tools for a hairdresser or changing winter tyres for a car mechanic.

Second, different modes of alternation are defined by the degree of (non-)integration of school and workplace activities

- **The school is distinct from the company**. In the standard dual model, the school and the workplace are separate institutions. The school teacher and the in-company trainer generally know each other, the teacher being usually a former colleague of the in-company trainer. As the teacher may be following 3 classes of 16 apprentices, this means there are up to 48 in-company trainers, fewer when large companies hire several apprentices. Direct interactions between the in-company trainer and the teacher mostly go through the apprentice. This triangle teacher-apprentice-trainer relationship is at the heart of the Swiss VET system but, paradoxically, it is an under-exploited channel. The story of how our platform Realto attempted to exploit this channel is described in Chapter 4.
- **The 'company inside the school'** describes those schools that include workshops that substitute the workplace experience. This is the case for some professions, such as clothing designers, with whom we conducted several experiments. To approximate the real workplace experience, students produce real pieces that have been ordered by customers. For instance, the director of the Technische Fachschule Bern, Matthias Zurbuchen, told us his school produces about 2 million Swiss francs of clothes per year. He explained that some large companies do, of course, work with Asia if they have to order 20,000 pieces but consider it faster to work with the school workshops if they want to order only 20 pieces or less. Despite these efforts, the experience of a company-in-the-school remains different from a real company, with its distinct culture and identity, and variety of professions. We tested our AR system for gardeners with a similar school in Sion which receives young people in difficulty from the French-speaking cantons. An informal observation was that our concrete technologies were even more appealing for these special needs teenagers than for the general population.
- **The 'school inside the company'.** Some companies formed an alliance to have private schools dedicated to their specific training needs. One example is Aprentas in the Basel area. The north-west corner of Switzerland is a world-leading centre for chemical and pharmaceutical companies. Three leading companies, BASF, Syngenta and Novartis, created a non-profit organisation that has expanded to include 70 other companies. They train 500 apprentices annually in 15 different professions, such as lab technicians and automation engineers. Vaccine production needs good automation! This organization has been recognised by the cantonal and federal authorities. This shows how much the VET system moulds

itself to the local economy. Similarly, a professional association in the health sector has launched the XUND centre. The association brings together many actors in the health system in central Switzerland: hospitals, nursery or elderly houses, house care and medical businesses. They train 2,700 apprentices in 17 professions, ranging from assistant nurses to technical aspects in health institutions. In other cantons, the apprentices of these two sectors might attend a public school. These examples of private influence on the VET system do not choke it in this liberal country as they would be in some neighbouring countries. The alternation in these centres is a mix of the two previous models, with workshops being held in the centres, but also activities continuing in the partner companies.

So far, we have discussed the VET system in Switzerland being a dual one. This is not false, but it is only a gross generalisation. Besides schools and companies, there is one more training location in the Swiss VET system, the so-called **intercompany courses (or branch courses)**. These are courses organised by professional associations on their own premises, premises that often provide equipment that schools or SMEs cannot afford. They constitute the missing link between the school and the company. They have yet another timing structure, running typically over one week twice a year, but in other professions, the number of days is fewer or may be scattered over the year. They provide mostly practical activities but also more theoretical lessons. They bring together apprentices from various schools from the same region. Some centres also bring together apprentices from several professions acting within the same sector, for example, painters, carpenters and bricklayers for the construction sector.

Diversity

As illustrated in the previous section, the Swiss VET system is a highly diverse patchwork of subsystems. The format of the vocational process varies by profession, canton and language. This diversity can be interpreted as having an overwhelming complexity or as the side effect of effective adaptation to local needs, as illustrated by Aprentas or XUND. Both features are indeed correct. Overall, it reflects a political culture of local independence that allows the adapting of solutions to local contexts. Switzerland is a truly federal country. The federal government is composed of seven councillors, one of whom becomes the country's president on a yearly rotation, which contrasts with other federal countries such as the US and Germany. No less than 7 cantons have less than 100,000 inhabitants. Local really does mean local in this context. The country does not have one minister of education, but 26, that is, one per canton. Compulsory education is managed totally by the cantons. At the federal level, the minister of the economy is also in charge of education and research, a trait that would make any French sociologist go crazy. They nominate a state secretary for education, who leads, besides other things, the federal office in charge of vocational education. This office updates the curricula (training ordinances) for every profession every five years. This process is done in collaboration with the Swiss Federal University for Vocational Education and Training (SFUVET) and with the respective national professional associations, which form their propositions after consulting regional or cantonal associations. We will argue in Chapter 9 that five years, however demanding, is quite a short time compared to the evolution of trades and how AI methods could accelerate this process. In compulsory education, a coordination of the curricula per linguistic area was only implemented 10 years ago, after 40 years of cantonal resistance, so it is quite an achievement to define curricula at the federal level. Even when curricula are defined at the supra-cantonal level, the funding is mostly cantonal (most taxes are cantonal), which is a permanent source of tension between the federal and cantonal authorities and partly explains the existing diversity. The resources for VET schools, such as learning technologies, can, therefore, not be decided in a top-down way at the federal level for the better or for worse. Bern is not Paris. Every canton or association chooses the technologies for its apprentices. This local autonomy generates complexity and is an irrevocable part of the Swiss political culture.

This local autonomy also characterises the corporate world. Switzerland may be known for a few leading multinationals, but the core of the economy is its myriad number of SMEs. The development of VET and SMEs go hand in hand: if a company has 20 employees, it can hire an apprentice despite that it may lack a formal training unit. Let's take a carpentry firm in the Vaud canton. It probably belongs to the association that has similar companies in the French-speaking part of the country and interact with their counterparts in the German-speaking region. It also probably belongs to the 'Wood Group' – the canton than brings together carpenters, joiners and cabinet makers, which itself is a subgroup of the cantonal Federation of Entrepreneurs, comprising all construction companies. The 'Wood Group' will have connections with the 'Centre Patronal' of the same canton and maybe the local Chamber of Commerce and Industry, as well as USAM, the national association of SMEs. In other words, the corporate side of VET is as complex as the education world. The good news is that these actors are generally concerned about VET. We have given many talks to their cantonal or federal annual assemblies. In several professions, the professional documentation that apprentices have to acquire is developed (and sold) by some of these associations. We have argued for years that they could also fund the development of digital resources, an idea which is now getting increasingly accepted.

Identity

These modes of alternation are not equivalent in terms of the identity developed by the apprentices. In the weekly mode, the electrician apprentice working, for instance, for the main Swiss railways company, called CFF, will rapidly consider himself or herself as a CFF employee rather than as a student. The same feeling of belonging does not exist when school dominates the apprentice's life.

This identity plays a key role in the vocational education system. One carpenter told us he had nothing to do with joiners. In reality, carpenters make houses and roofs structures and stairs; joiners make stairs, windows and cabinets. The boundary between them is really not clear. In the Vaud canton, they actually have formed a joint association. The daily work overlaps but their identity is different. Walking on a roof beam five metres above the ground is a typical carpenter's signature. When we visited worksites where everyone spoke French, we had difficulty understanding carpenters as most pieces in a roof structure have a specific name: Wikipedia has a lexicon for carpenters with 478 terms that no French speaker would understand unless they were carpenters. Speaking the professional dialect is one aspect of identity. Every profession also has its dress code: a suit and tie for clerk office apprentices, and a helmet and work overalls for others, coloured white for painters and plasterers. When you see an apprentice at a train station, you can almost guess which trade he is learning. It looks as if these teenagers have all read Lave and Wenger's book (2001) on 'legitimate peripheral participation'.

We are convinced that the development of a strong professional identity has a positive effect on apprentices, both as a motivation for the school element and by enabling a smoother integration in the workplace. We inferred that the learning technologies we developed should have some identity elements. For our online platforms, we adopted the graphical layout of their professional organisation. In teaching statics to future carpenters, it was clear to us that they had to manipulate wooden structures, plastic ones being cognitively equivalent but awkward in a carpenter culture.

Teachers and in-company trainers

School teachers and intercompany course teachers are part-time or previous professionals in the domain they teach. They usually know the local companies in their field, their practices and the machines they use. However, some may have left the corporate world for a long period and their expertise may slowly drift away from the methods or technologies used on a day-to-day basis. One carpentry teacher told us this anecdote: when he gave his first school lesson, an apprentice asked whether he became a teacher because he went bankrupt. Teenagers can be cruel but this reflects a reality.

If a professional in X wants to teach X in a VET school, she or he has to do 1,800 hours (60 ECTS credits) of training. The in-company trainers need to follow a lighter training schedule. In both cases, they benefit from being introduced to learning technologies through some specific modules. However, the impact of these modules remains limited. We have seen the same phenomenon in pre-service teacher training: if during their three years' training, covering about 60 courses, a student gets 2 courses devoted to learning technologies and 58 courses on other topics that do not use any technology, the message they receive is clear. *'it's good to know about them, but you don't have to use them'*.

Learning documentation

During their training, apprentices have to complete some kind of portfolio that summarises their main professional achievements. This documentation is also part of their final assessment. Practices here do, however, vary a lot across regions and professions. Bakers and cooks, for instance, will document a certain number of recipes; electricians will detail the quotes and actual realisations for customers. All of them have a template to fill in. It is the in-company trainer who has to make sure that the apprentice duly fills their documentation but not all of them fully assume this role. In some cases, it is perceived as an admin duty. This is however a central element in the Swiss VET system and we included it in our digital approach.

Exporting VET abroad

There have been many attempts to export the Swiss VET system to other countries. Numerous foreign delegations came to learn more about it, but we do not know of any clear success for transfer. The cause relates to what we explained earlier: how deeply is the Swiss VET system rooted in the political culture and the local economic tissue. Once a carpenter told us, '*I don't need an employee but I took an apprentice*'. We asked why and he replied, '*because I am a carpenter, it's our duty to do it*'. This collective feeling of responsibility, another trait of Swiss culture, cannot be simply expected from SMEs in a country that does not have the same tradition. There have been attempts to implement a dual VET approach around large Swiss companies that have factories in China and USA, namely in Colorado and Connecticut, below. The two last US ambassadors in Switzerland visited our lab at EPFL. But even if a CEO is convinced, the rest of the staff and the local schools need to be on side, not to mention the parents, who would have difficulty understanding what it means for their kids to do an apprenticeship.

Even if our leading house focused on Switzerland, we brought to Kerala (India) our tools for training carpenters. This was an AR environment for developing 3D reasoning skills required to cut wood beams to make a roof (see Chapter 7). We discovered that wood is too rare and precious in India to make something as big as a roof. This illustrates how difficult it is to transfer a learning technology across contexts. We will not change an economical culture by launching a project, however ambitious. We have to remain modest and realistic about what can be exported. We do, nonetheless, hope that some of the technologies we developed can be used in other contexts without implementing cultural change as a prerequisite. If this was the case, they might convey fragments of the Swiss VET culture as a Trojan Horse to other VET systems.

So what?

Once the HR director of a Geneva private bank came to visit us and here is more or less the dialogue we had. Let's call him Jean.

Jean	We need to use learning technologies for training our staff.
Pierre	Why?
Jean	We need to innovate, all banks move to digital training!
Pierre	Do you have a problem?
Jean	No, we are a private bank, we have no problem.
Pierre	Then come back when you have a problem; we'll search for solutions.

This dialogue was followed by a great deal of collaboration. Should we ask the same question about the VET system? The best way to launch a project is to start with a problem. There is a general trend among Swiss stakeholders to praise their VET system. Honestly, it deserves it. But this is not a reason to ignore that it also has its weaknesses. The system is as good as it is because it is constantly seeking improvement. There are some general problems, such as the skills gap that we described previously, the delayed age of starting an apprenticeship, the drop-out rate (the rate is not high but every case is a painful story), the percentage who do not get the full apprenticeship, but a lighter form in two years (called Federal VET Certificate), and some in-company trainers who do not play their training role or are just nasty bosses (as in any profession).

Globally, the Swiss VET system is solidly anchored in a long tradition of apprenticeship, but traditions are sometimes not an advantage in a fast-moving economy. Any feature of the system can be interpreted both as an asset and a pitfall. For instance, the strong involvement of professional associations in designing curricula helps produce worker profiles that fit specific market needs. The problem is the word 'specific'. What about mobility? Müller & Schweri (2015) found that only 7% of apprentices change to another profession. This mobility is expected to increase in the coming years with the emergence of new jobs and the vanishing of other ones. Should the florist association care if some of its trainees later decide to be bakers or nurse assistants? The Swiss VET system is somehow siloed. Some of the emerging skills might increase mobility: computational thinking skills, data analysis skills, manufacturing skills. The latter (3D printing) now applies to multiple professions, printing in wood, iron, plastic, chocolate (bakers) and other materials (e.g. dental prostheses).

Not all problems are solvable with digital technologies, of course. There is a long road of discussion with all stakeholders to identify a 'good' problem. If one simply asks teachers, they might reply that young people are less motivated, distracted by their digital gadgets or unable to write a simple text. Passing beyond these commonplace problems takes about six months of interactions. Down the road, we identified and tackled a bunch of problems. Here are four examples:

- Optimising warehouse storage is a skill that logistics assistants have to acquire (it is an objective of the federal ordinance) but they rarely practise it in the workplace: the warehouse is not reorganised very often and, when it is, it is the warehouse manager who decides it, not the apprentice. We visited many warehouses; apprentices operate in them, but they do not reorganise them. Therefore, it is quite hard for apprentices to give meaning to the logistics principles presented by the teacher. Teachers asked if we could do something about this. The TinkerLamp (see Chapter 6) was developed to address this skills gap.
- Future carpenters spend about three hours per week over three years learning how to draw plans on paper. They routinely acquire methods for representing a 3D structure on a 2D plan, such as computing the true length of a segment through rotation. They repeat the procedures many times, as a pure procedural skill. Teachers expect them to reach millimetre accuracy. Visiting many carpenters, we realised apprentices do not draw the plans of the roofs they are working on: their boss does it. In fact, their boss does not draw on paper, he uses 3D software. We asked these bosses if apprentices should then stop drawing at school, but they rejected the idea. They said an apprentice faces a 3D structure with a 2D plan in their hands: she or he must learn to go back and forth between the 2D and 3D

representations. The TapaCarp (see Chapter 7) environment was developed to address this skills gap.

- A new ordinance came in during the life of this leading house by which carpenters now need to develop some intuitive understanding of statics. The new curriculum included three hours for learning what engineers acquire in hundreds of hours. How does one teach basic statics without mathematics? Our civil engineering colleague said it was not possible. The StaticAR environment (also in Chapter 7) was developed to address this skills gap.
- In our discussions with the professional associations of the bakers and the chefs, it became clear that their members were getting confused about all the documents that had to be completed during training: the classical recipe book, the newly introduced learning documentation (LD) and the regular work reports. We then agreed that these documents could become one single document with different pages linked altogether around each recipe or technique. Moreover, they were happy to see that technologies could also give the recipe books a more attractive 'look', with multiple pictures easily inserted directly in the texts, no longer being clipped into handwritten documents as before. LearnDoc, e-DAP and Realto (see Chapters 3 to 5) incorporate these facilities.

In summary, the Swiss VET system has solid roots, but has also enough problems to inspire creative researchers and start-ups in the area of education technologies.

Chapter 2

Learning technologies as a powerful way to turn alternation into an opportunity to embed theoretical knowledge in practical experience: The Erfahrraum model

Alberto Cattaneo, Jean-Luc Gurtner

In the dual VET model, apprentices regularly alternate between their company and the vocational school throughout their training. They usually see what they face here and there as disconnected, a perception that is sometimes correct. We met car mechanics in their first apprenticeship year who were mostly occupied in very concrete activities such as changing tyres in their garage or facing physics problems at school. Chef apprentices were challenged to be as fast as possible in preparing 400 meals at once every day in a hospital misaligned with the idea to know what kind of protein albumin is and which of its properties are relevant for cooking. Gardeners carefully driving their lawnmowers felt obliged to learn by heart the characteristics of hundreds of plants. Logisticians moving boxes all day long in a warehouse were at pains to understand abstract concepts being addressed at school, such as the optimisation of the flow of goods. We could continue providing examples for each of the professions we worked with. The conclusion is always the same: dual VET programmes are full of gaps between the school and the workplace. Researchers often refer to this as a connectivity issue. Specific pedagogical approaches have already been developed and tested to face this challenge, such as the integrative pedagogy model by Tynjälä et al. (2021) or the connective model by Guile and Griffiths (2001). Those who want to have an updated overview of these models can easily refer to a couple of recent books dedicated to this issue (Kyndt et al., 2021; Aprea et al., 2020). Our point is that these gaps are not only constitutive of the dual VET system, they are also essential determinants of its quality and value. Therefore, we do not want to reduce these gaps to zero. This would distort the nature of the system itself. But we would like to make them more functional and find a good way to take advantage of them. After all, the same is true when crossing a border between two countries: at first glance, the differences may seem somewhat disturbing, but once you get used to crossing it, you will find some benefits in the situation, as all border crossers know.

Our main and umbrella question for our research programme evolved from the evidence of this gap. It developed from the question, ‘Is there *a specific way* to use learning technologies in VET?’ to something like, ‘Can technologies make a significant contribution *to bridging the gap* between learning at school and learning in the workplace and turn the situation into something profitable for learning?’

Implicitly, our hypothesis is that *technologies can optimally be used as a bridge for the above-mentioned gap and make it relevant to learning by facilitating the integration of pieces of knowledge from different learning locations*. In other words, technologies can become ‘boundary objects’ and facilitate boundary crossing across learning locations (Akkerman and Bakker, 2011; Bakker and Akkerman, 2019). When speaking about crossing boundaries, we refer to social and cultural rather than physical boundaries, which are at least initially perceived as discontinuities, but which can constitute an important potential for development, precisely from the perspective of connecting the apprentices’ experiences across learning locations. Boundary crossing is thus the effort to develop, establish or re-establish continuity in the action or interaction between different practices that are experienced by the same person in different contexts (Bakker and Akkerman, 2019). In other words, crossing boundaries repeatedly, virtually and physically, could be an effective way for apprentices to better perceive the common thread linking tightly what they study at school to what they experience in their working lives.

This gap between what is done at school and what is experienced in the workplace can take various forms depending on the profession encountered, the topic to be learned and the kind of learning technology activated. The next six chapters illustrate this diversity and the various solutions we adopted with nine different professions, belonging to very different professional domains and horizons. All of the situations we explored can be related, partially or fully, to the same model, which we call 'Erfahrraum' – a neologism resulting from two German words bumping into each other: *Erfahrung* – for 'experience' – and *Raum* – for 'room, space'. The Erfahrraum is simply grounded in an idea already exploited for decades in the learning sciences: you can learn from your experience provided you have the time, opportunity and conditions to reflect on it. Reflection is an essential, yet not a sufficient, condition.

The Erfahrraum model

From the first day spent in a company, apprentices live out various professional experiences. Some of them are more meaningful than others, but all are rich, complex and authentic! We pedagogues often preach that competence can only be achieved '*in situ*', that it is only in a situation as it occurs where competence can be exercised and thus matures. What better opportunity to foster the development of an apprentice's competencies than one where it recurs in their experiences? It is from this simple realisation that we developed our model. We mulled over it several times in our project meetings and progressively re-discussed and refined it in a continuous and generative reciprocal dialectic between theoretical reflection and practical testing. We finally published it (Schwendimann et al., 2015); but, to put it simply, although its starting point can vary and its implementation can be iterative, you can think about the Erfahrraum as a four-step model, as the four quadrants of Figure 2-1 illustrate.

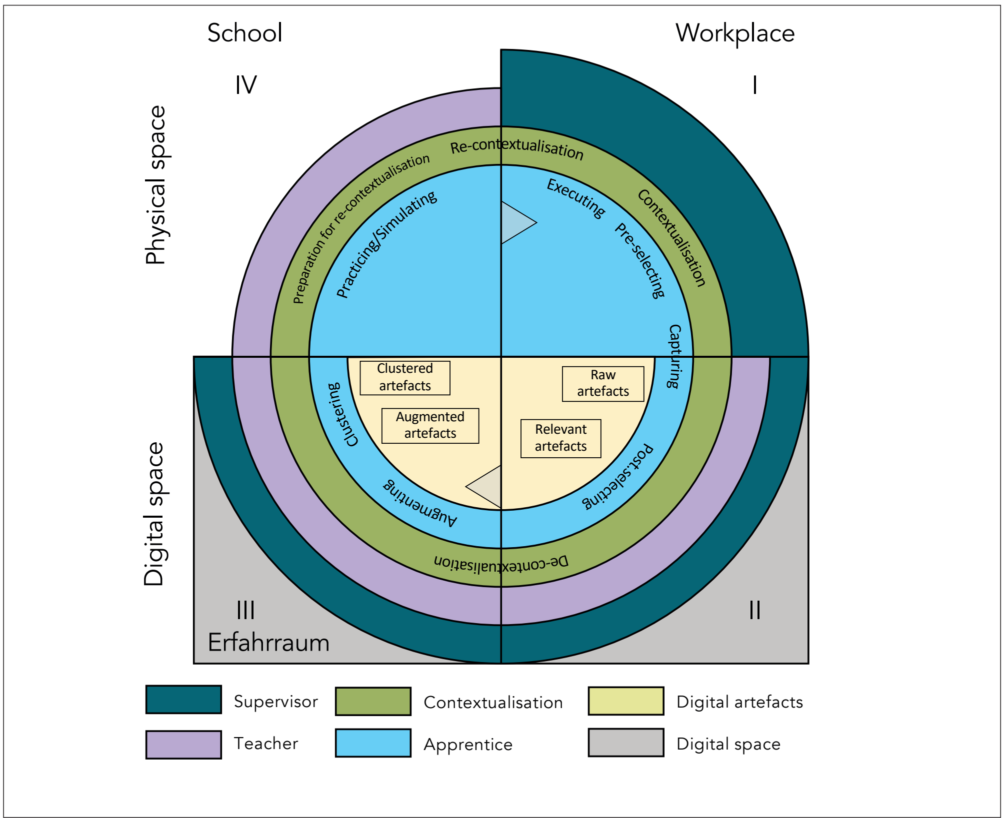


Figure 2-1 · The Erfahrraum model

We describe it simply as follows:

1. **Capture and collect.** The first step usually corresponds to the trainees living their professional experiences and carrying out certain procedures. We said that an essential component of our model is reflection, but in the workplace, there is usually no time for reflection. You have to be productive and fast and avoid mistakes and wastefulness. Therefore, it can be useful to find ways and forms to capture

some *'traces of experience'*. Technologies – especially mobile devices – can help to this extent. Thanks to digital tools, capturing an experience can take place when and where it is happening. Think about giving your apprentices the chance to use a smartphone to take pictures in the workplace or to wear an action camera to video record them performing a procedure. These traces then take the form of photographs, short videos, audio recordings, notes or written descriptions or sketches, which externalise the apprentice's experience and produce raw digital artefacts that can be reconsidered *a posteriori*.

This first phase brings with it some further considerations which are worth mentioning here in relation to the 'traces'.

a. As such, they constitute a sort of *anchor*, a concrete link to the lived experience. They, therefore, constitute a useful reminder to re-contact the experience and generate reflection. We have said how difficult it is to reflect on one's professional practices. To have at one's disposal a set of pictures showing the experienced situation is a good starting point when triggering the reflection mechanism.
b. At the same time, traces are *evidence* of what happened. Collecting them means documenting what has been done, what has been learned. There are at least two values, the first showing the variety of procedures that one has been able to deal with throughout the apprenticeship, as a kind of portfolio showing the work done. In this portfolio, I can decide to select only my 'masterpieces', rather than just give an account of the whole range of activities that I have had the opportunity to manage during the apprenticeship. The second value, consequently, shows the progress made in terms of competence development. Documenting similar practices over time allows you to realise how your competence mastery has developed over the years. As a baker, for instance, if the first time I made croissants I overcooked them, even risking burning them, the second time I can show (both to myself and my trainer) that I was more careful about temperatures and cooking times, and that I have improved my mastery of that particular procedure, identifying the essential critical points to watch out for.
c. From a pedagogical point of view, finally, it is valuable to consider that keeping these traces is not immediately a spontaneous process. Especially at the beginning, it needs guidance and scaffolding, and it has to be stimulated. The learner must also *manage selection* processes; as said, not all the experiences are worth documenting. The apprentice has to learn what to document and what not, what can be meaningful for learning and what can be omitted.

2. **Prepare.** As we just said, not all experiences are meaningful for learning just because they can be captured. To turn them into learning material, apprentices will have to enter a selection process as well as a *structuration* one. Such a structure can be provided by the teacher or directly by the digital learning environment where the traces are collected as we will see in the following chapters. In-company trainers also can help by offering their apprentices the possibility of making such meaningful experiences and paying attention to what exactly happened. But they often do not have time to discuss it carefully in the company itself. The work must go on. Imagine something got broken or burnt. You would have to start again, possibly under tighter control, rather than pause and reflect too long on what exactly went wrong. You might even be given something else to do while your trainer took care of redoing it properly!

3. **Exploit.** At school, on the contrary, time is more flexible and errors have a more positive status. Provided you have kept traces of what went wrong in the company and can access them at school, you might have a chance of discussing them more thoroughly there. In Schön's terminology, this possibility is called 'reflection on action' (Schön, 1987). But how do we imagine this process being practically conducted in VET lessons at school? We certainly do not imagine droves of apprentices spending hours speculating in the abstract about what they have experienced in their company, nor going back again and again on video recordings of their own practice at work. No, we mean much simpler but still very effective activities. Let us take a few examples. Think about how many things are happening around us that we are not aware of. It is normal because our attention primarily selects

the information that seems most relevant and functional at that moment. But in order to hone and improve our professional skills, it may also be important to pick up some of the information that we missed in the live action. This is what we tested, for example, with surgery room technician students, giving them the opportunity to review the video recording of their activity in the operating room and use it to prepare and structure debriefing sessions with their tutors using video annotation. Both parties involved acknowledged that without the video, many details would never have emerged in the debriefing discussion (Cattaneo et al., 2020). A similar approach can be used also with pictures, annotating them to train apprentices' professional vision development, as we did with beauticians, to support them learning about skin anomalies (Coppi & Cattaneo, 2021; Coppi et al., 2021). However, there are situations in which it is simply not possible to video one's own practice. Anyway, it will always be possible to try to reconstruct it by describing it, either orally or in writing. This description can be analysed to obtain further details as well as to identify room for improvement. We have done this with a number of classes of commercial employees, asking them to compare themselves in pairs and using some guiding questions to facilitate the task (Boldrini & Cattaneo, 2014). This comparison of practices could also take place in other ways, in small working groups rather than in plenary sessions. For example, chef apprentices could work in a low-starred restaurant as well as in a big dining hall or a cafeteria. They deal with the same cooking methods, but with different tools, a different division of labour and different rules. Comparing how a similar procedure is conducted in different professional contexts is very helpful for developing a professional competence. The same positive effect can occur when analysing routine experiences together with rarer ones, or experiences in which some errors occurred with paradigmatic reference models (Cattaneo and Boldrini, 2016; Cattaneo and Boldrini, 2017; Wuttke and Seifried, 2012). These *contrasting* activities (Schwartz and Bransford, 1998) allow for the comparison of distinct cases (experiences) by similarity or difference, which can then be grouped according to specific categories. These categories are the ones which allow experts to identify the patterns that link to each apparently different situation (Bransford et al., 2000) and that are at the heart of competence and professionalism. Moreover, these processes of *enrichment, comparison and categorisation* support the construction of decontextualised (Guile and Griffiths, 2001; Griffiths and Guile, 2003) and generalisable knowledge. That we speak about reflection 'on action' also indicates that the object of our attention is an experience already lived and not currently happening.

To sum up, in this third phase, educational activities aimed at generating learning from reflecting on the professional experiences captured in the previous phases are carried out, regardless of whether these experiences have been lived in the first person by all or only by one member of the learning community, and of whether they have been authentic or simulated. These activities can be developed by exploiting some typical processes, such as those of enrichment and comparison and contrast. Raw artefacts are 'augmented' through the addition of successive layers of information, for example, by focusing attention on relevant information or by integrating comments and analysis by community members, or by adding elements of theoretical knowledge to practical experiences as a result of a discussion orchestrated by the teacher.

4. **Validate.** The fourth phase prepares for the recontextualization (Guile, 2020) of knowledge in the professional activity. It also includes the organisation of opportunities to apply what has been acquired through practical exercises and activity simulations. Such exercises further allow the link with the disciplinary and theoretical knowledge addressed in the school context to be made more explicit. In addition, at this stage, factors such as quality, speed or the satisfaction of those involved may indicate whether the passage through the four stages of the model was effective. Ideally, then, this last phase does not stop in the school context, but concludes with a return to the professional context, where it must be possible for the trainee to *validate* through a new professional experience what he or she has acquired through reflection in the previous experience. This is how the whole cycle finds completion and meaning, including in the eyes of the learner.

So what?

Weekly alternation between a company and a school is a trademark of the dual vocational education model. It is its strength but also one of its biggest challenges. Obviously, apprentices rarely see the connections between what they are presented with here and there and tend to view the situation as two parallel tracks rather than a homogeneous training path. Moreover, for the vast majority of apprentices, the workload may be heavy but justified by the profession while the school activities are less motivating. In this book, we hope to show that modern learning technologies offer many practicable solutions to alleviate that impression, narrowing the gap between the two tracks by opening transversal roads or bridges connecting those tracks and allowing apprentices to see the theory taught at school as clearly embedded in their everyday practice, as rooted in their workplace experience. Of course, this does not come simply from the technology; it all requires intelligent uses of these technologies by teachers and trainers, as well as productive learning scenarios, such as the ones we describe in the following chapters.

Chapter 3

Collecting and saving meaningful experience: The bakers' and chefs' stories

Alberto Cattaneo, Jean-Luc Gurtner, Elisa Motta, Laetitia Mauroux

While all their performances at school are evaluated by the teachers, apprentices' accomplishments in the host enterprise are discussed each semester with their VET trainer on the basis of the learner's actual performance and behaviour at work as well as the quality of their 'learning documentation'. The learning documentation is a compulsory production to be elaborated on by the learner throughout their training in which they describe and document the important accomplishments they achieved for the enterprise as well as the competence and the experience acquired so far (ref. Section 7 of the ordinances for all the professions). At the time we started our project, this learning documentation was generally done by hand and presented mainly as short texts written on independent paper sheets. The professionals and apprentices were unanimous: this was more an incentive to judge the learners' spelling competence than a basis for a real discussion of their competence in progress.

In the three professions we were in close contact with – bakers and chocolate makers, chefs and clothing designers – the required learning documentation even interfered with another traditional written production apprentices were supposed to elaborate on during their training as a reminder – their recipe book or production catalogue. Such handwritten documents had really nothing to do with the nice looking and highly attractive recipe books flourishing in bookstores and no apprentice would be proud of their documents, neither their learning documentation nor their recipe book. After discussions with the professionals and with their professional association, it became clear that technologies could make their documentation more compelling by use of text processing and photos inserted directly in the text, be their photos taken on the spot or downloaded from the Internet (Figure 3-1).

Figure 3-1 · Apprentices at work, collecting pictures to insert in their learning documentation and recipe book.

We also decided to use appropriate and systematic templates, both for the recipe book and for the learning documentation, convinced that the filling of these documents would be more convenient than having to start over from scratch as was the situation before (Figure 3-2). Finally, we also rapidly agreed that technology would make it easy to combine learning documentation and recipe books in a unique electronic documentation, showing on one page the target recipe and on the reverse side, the apprentice's current level of mastery and struggles in completing it, with the possibility of alternatively hiding or displaying one or the other, depending on who might access the pages.

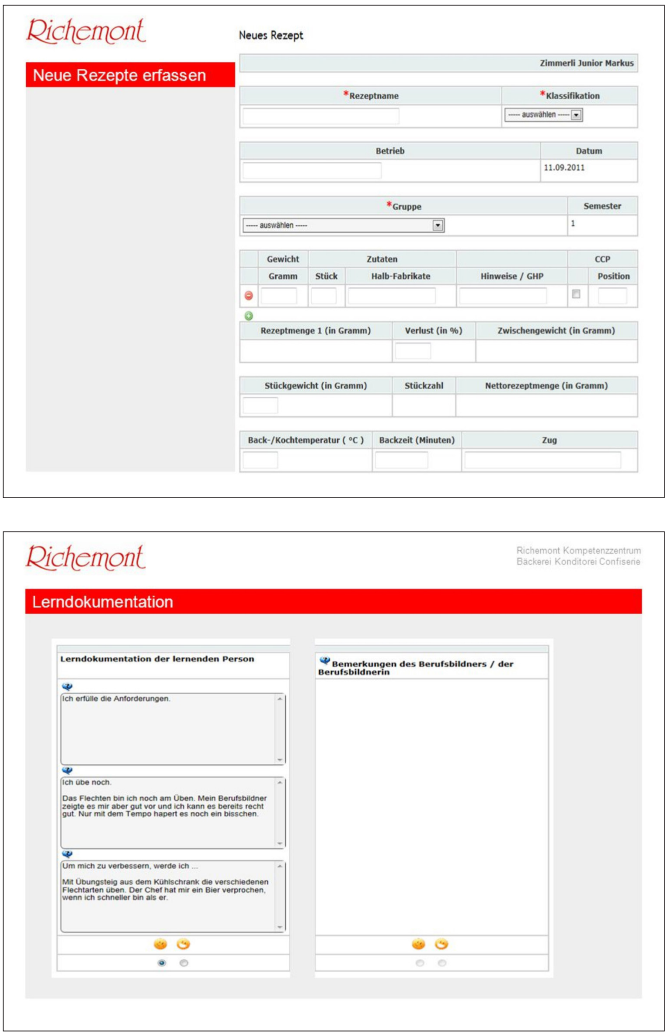


Figure 3-2 · Templates adopted for the recipe (top) and for the learning documentation (bottom) as discussed with the bakers and chocolate makers' professional association.

The chef's story

Nicola Piatti is a professional chef, who has been working for many years in important restaurants. He is also a professional teacher, after, at a certain point in his career, the canton called him, asking him to teach apprentice chefs in the vocational school in Trevano. The first time we met him was in 2009, when we were still early in the project. Yesterday, at the end of August 2021, we were still in the same classroom, training – with Christian Gianetti, also a former chef and in-company trainer, and now full-time teacher, who, in the meantime, joined us – twentysomething teachers to use what we developed in the last ten years. Let us summarise this collaborative story in the following pages.

In the first discussions with Nicola, many possible topics intersecting with our reciprocal interests emerged. The two main themes that emerged were better connecting the workplace and the school and finding appropriate ways to collect and give meaning to workplace experiences. We hit on a concrete topic that combined these two themes: a rethinking of the students' recipe book and its articulation with the students' learning documentation imposed by their training plan.

As already explained, this last point immediately caught our attention, and we started deepening it in parallel – the team in Lugano worked with chefs and started from the school while the team in Fribourg continued to work with the bakers, focusing mainly on the in-company trainers. In Ticino we called it e-DAP (*documentazione dell'apprendimento e delle prestazioni elettronica*). Each entry constituted a recipe, made up of two main parts, like a recto-verso paper sheet. On the ‘front’ side, apprentices could include all the general information concerning the procedure, from the list of ingredients to the description of the main cooking steps. As in many online recipe books, they could equip each recipe with as many pictures they wanted (see Figure 3-3). To support this process and to exploit the ‘collecting’ phase of the Erfahrraum, we bought 24 second-hand iPhones, so that all the pupils in one of Nicola’s classes would get one. A pre-installed app allowed them to connect the pictures in the smartphone to the e-DAP, uploading and correctly associating the pictures to the recipes.

Figure 3-3 · Examples of raw traces photographed at a workplace by apprentice chefs. Each row corresponds to a set of pictures detailing the main steps of the related cooking procedure.

On the ‘rear’ side of our imaginary sheet, as described above for the bakers and chocolate makers, a series of metacognitive prompts (see details in Mauroux et al., 2013, 2014) helped the apprentices reflect on their current mastery of the recipes, identify the possible improvements, understand what went wrong, and so on. This also allowed us to investigate the ‘exploiting’ part of the Erfahrraum. On top of that, apprentices could self-assess their performance and ask their in-company trainers for recipe-specific feedback (also including an assessment), as well as get an overview of their competence development progress through a summarising table which provides paired assessments per each recipe (see Figure 3-4).

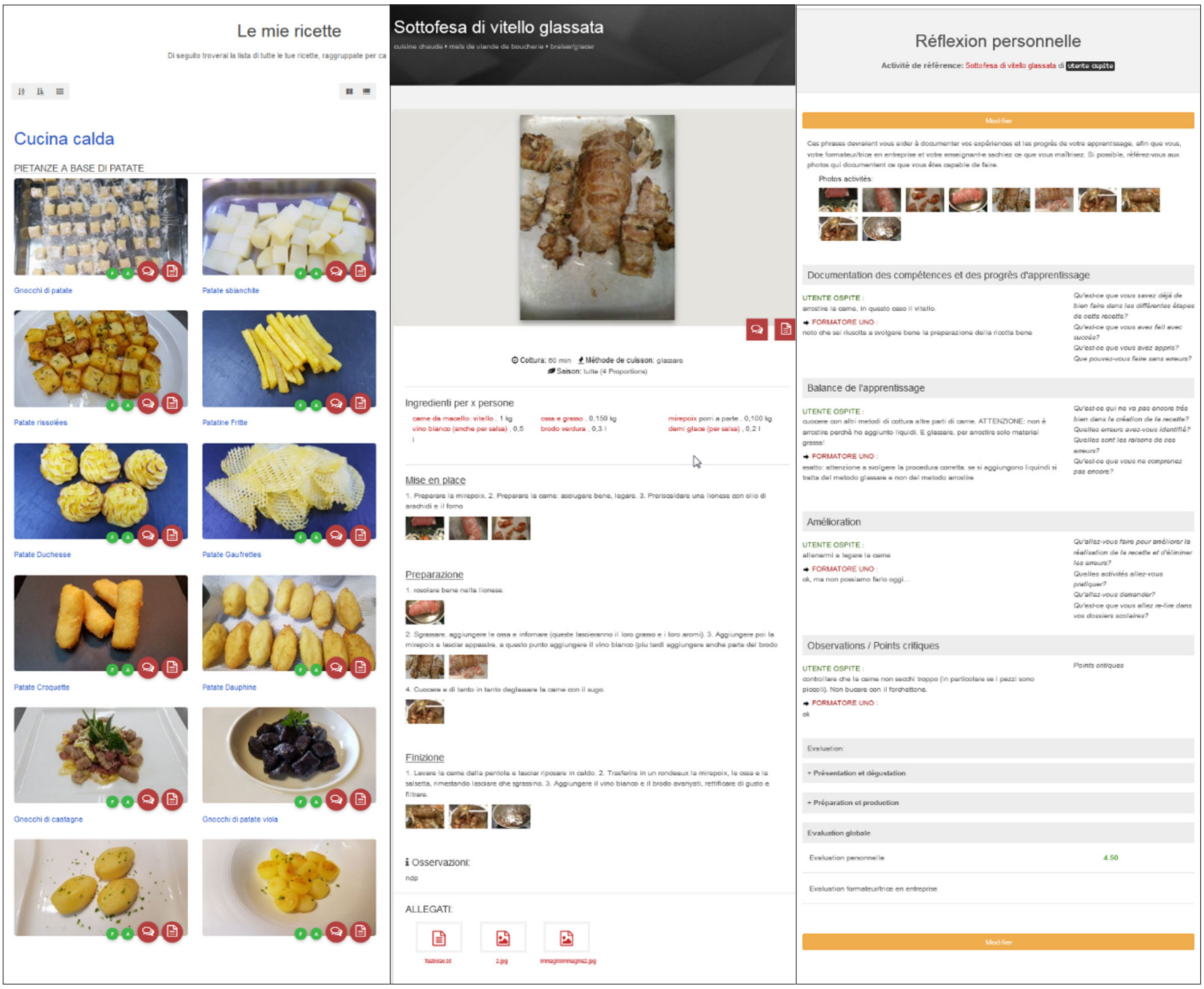


Figure 3-4 • The e-DAP environment for apprentice chefs to collect their learning documentation in the form of a recipe book.
Both their vocational teachers and in-company trainers could access the same environment, albeit with different privileges. The entry page (left) shows the developed recipes. Each recipe (centre) has the necessary details, as pictured in the apprentices' photos. And each is completed by a reflection sheet (right). This sets the basis for self- and trainer assessment. Note that the traces (pictures) are also available on this page to support the connection with the practice.

As the reader can infer, the host company trainers also received an account to the e-DAP, from which they could check their apprentice's progress and provide them with an assessment and feedback.

Then we prepared an official letter to inform the in-company trainers about the project and its purposes. Elisa Motta – our PhD student on this project – started to drive her car around the canton together with Nicola to meet the company trainers and deliver the smartphones to their apprentices in their workplaces. They showed them how to use the phones and how to access the e-DAP.

In the meantime, Nicola also enrolled in the teaching diploma programme. So, the idea emerged to exploit the e-DAP at school also to bring specific professional situations into the classroom and thus introduce the raw visual traces from the apprentices' workplaces experiences from the workplace into the school, a development that was not foreseen for the bakers' and chocolate makers' platforms.

Everything was set to monitor what would happen.

Co-designing learning scenarios

We continued discussing various issues with Nicola, but at this point, the object of our talks was no longer the skills gap; the topic now had become how to take advantage of the materials available in the e-DAP when planning lessons. We then started developing various learning scenarios (where apprentices could be involved individually, in small groups or plenary sessions), all based on the use of that tool and the implementation of the Erfahrraum. For example (for other learning activities, see Hämäläinen & Cattaneo, 2015, and Motta et al., 2017), a couple of weeks before treating the topic in the classroom – chefs in Ticino attend the school courses two days every other week – the teacher invited apprentices to practise a particular cooking method (with any recipe) and to document it in their recipe book and (this second step was progressively introduced) in a corresponding learning journal page. This process had to be illustrated by pictures, or, in some cases, even by short videos recorded using a headband camera. In this way, Nicola could look at the recipes before the lesson by simply accessing the learners' e-DAPs. When all the apprentices then gathered back at school, Nicola invited one of them to sit at the teacher's desk and illustrate their experience, with the support of their e-DAP traces. This was enough to trigger a rich and passionate dynamic of confrontation, disputation and sometimes positive competition among the apprentices, the whole orchestrated and specified by the teacher, who was always in charge of guiding them to identify the main and crucial points of the cooking method. In the discussions, indeed, the explicit knowledge concretely represented by the pictures was then linked to implicit, theoretical knowledge. On some occasions, the discussion itself could be reified and converged into a visual document, where the initial pictures taken from the e-DAP were labelled or coupled to facilitate comparison (Figure 3-5).

At this point, we wanted to know how effective this overall approach was primarily based on apprentices' learning. To do that, we profited from the fact that Nicola was teaching in two parallel classes, so we used one of them as the experimental group and the other as the control group. The content and general approach were the same in both classes, but the former could also profit from the e-DAP, which was not the case for the latter, of course. Let us see what we got.

STIR FRY PREPARATION

STIR FRY TOOLS/GENERAL PORTIONS

ROASTING PREPARATION

There are bones too!
A nice sliced piece of meat
leaft seasoning

Add meat and vegetables and then put it in the oven. Remove the meat before adding wine otherwise the crust will not remain crispy due to the moisture.

Adding wine in this moment (see picture) will make it "glazing" cooking method!

BRASING PREPARATION

STIR FRY					
			NURSING HOME	RESTAURANT	CANTEEN
MISE IN PLACE	Ingredients	Foodstuffs	French Breast Pork loin, veal breast (cheaper) Fillet of beaf (clients like it, iron...so we write it in the menu)	French Breast Fillet of beaf	French Breast Fillet of beaf
		Amount per portion	120g 80-100 g Depends on the menu (old people eat less)	189g You can choose the weight and course!	120-150g (You can choose since they're young (not old people) Type of client
		Total amount	10kg (x80people) Depends on the nursing home	180-200g	20-80 kg (x160) Depends of the meat
	Tools	Type of tool	Flippable brasier Combisteaemer	Anti-stick pan or lionnaise	Brasier Combisteaemer
		Dimensions	Big brasier = 100x50		
PREPARAZION	Cooking time/temperature		20-35 min	5 min max	20 -35 min
	Resting time		Cool down and regenerate?		Cool down and regenerate?
COMPLETITION	Serving time		Depends on serving time and number of people	Depends on serving time and number of people	Depends on serving time and number of people
	Garnishing		Clients don't like them, they take too long to make and cost too much	We have time and money to make them	We don't do them, they take too long to make and cost too much
OTHER	Healthy diet		Fat-free Degrease before adding sauce	We use fat! The flavour is much better!	Fat-free Degrease before adding sauce

Figure 3-5 • Examples of elaborations of raw traces as augmented artefacts during a class activity: pictures are commented on and labels are inserted to point out the crucial elements (top and centre left) or to contrast cases (right). Summary tables (bottom) are progressively compiled as a generalised result of the analysis.

Will they use it?

First of all, we wanted to know if the users found the system easy to use and then finally used it. That question was answered positively: e-DAP was perceived as being easily applicable and also useful for learning (Motta et al., 2013, 2014). After the first semester of using e-DAP, the average number of recipes developed per apprentice was 15, rising to 48 by the end of the apprenticeship (see Cattaneo et al., 2015, for details), all numbers that were far beyond those observed previously with paper and pencil learning documentation. A similar effect was also observed for the bakers and chocolate makers (Mauroux et al., 2016).

But we know that quantity is not necessarily the best indicator in many situations; that is why we wanted to have a look at the quality of their entries too. Regarding quality, we focused our attention on the learning journal entries, looking for and counting the average number of reflective elements added to the recipes. In most cases, the experimental class presented significantly more reflective elements in their learning journals than the control group (Table 1 in the appendix; for more details see Cattaneo et al., 2015). Further investigations confirmed that the reflective prompts were effective at supporting the development of our apprentices' metacognitive skills.

Will it be effective for learning?

Although metacognitive skills development is an important component of learning, especially for a vocational learner, one worry for Nicola – and for us too – was to verify if the new teaching method was effective also for declarative knowledge acquisition, a sort of first clue of learning. Therefore, several of the scenarios we implemented, both individual and collaborative ones, were designed to have measures of this component. Concretely, Nicola developed learning tests for each main cooking method. We submitted the tests before and after the learning activities so that we could both verify at the beginning that the two classes were comparable and compare them after the learning activity. Once again, what we found was that the class which had benefited from the Erfahrraum pedagogy outperformed the other one (Table 2 in appendix and Cattaneo et al., 2015).

This was also mirrored in the final rates achieved at the exams; even better, those who used the platform more intensively obtained higher rates (Mauroux et al., 2016; Schwendimann et al., 2018).

Although the exam already includes a practical part, we were not fully satisfied and wanted to further test whether such benefits also show up in practice. We, therefore, organised an experiment in the centre for intercompany courses. We invited a group of apprentices from each class to prepare the same recipe (chopped Zürich-style chicken) and gave them 25 minutes for it. Each apprentice had at their disposal one professional workstation, where the required ingredients were prepared in advance to be ready for use. They all were asked to do the recipe, think aloud and comment on what they were doing while doing it. A camera per workstation video recorded the participants' performances and comments. The clips were then shown to two professionals, experts in the field, who assessed each video independently, using a 27-indicator grid similar to the ones used in professional contests. In 22 out of the 27 indicators, learners from the e-DAP group did significantly better in their performance than those from the control group. And guess what: the quality of their reflection-in-action was also much higher than that of the control group! (See Cattaneo & Motta, 2021, for details)

And what about bridging the gap between learning locations?

At this point, one important piece of the puzzle is still missing. We started Dual-T with the question about the potential of technologies to bridge the gap between vocational learning locations. The Erfahrraum model had been effective with the chefs;

perhaps it could also be effective for this? And what about the vocational system itself? Luckily, we have some data on these issues too.

Developing the platform in this way, our hypothesis was that giving apprentices the possibility to exploit the added visual value of pictures both in the classroom – for sharing with the teacher and the schoolmates – and in the workplace – for nurturing discussions with the in-company trainer – constituted an aid for them for better perceiving the relationship between the two locations through the learning documentation (DAP). Its electronic form, additionally, would have increased the frequency of use for all the actors, and in particular, (a) for the teachers at school, despite the formal task of working on the DAP being not their one, and (b) for the in-company trainers, who often have no time to analyse the content of these dossiers.

We prepared and delivered a questionnaire for apprentices in different professions nationwide to investigate these hypotheses. Doing so, we had both the possibility to contrast what we were doing with the chefs with respect to other professions, and to see within the chefs' profession if the Erfahrraum-compliant approach was effective in different ways. Figure 3-6 shows that when asked about the potential of the DAP as a tool for better connecting the school to the workplace, Dual-T chefs differed from the other apprentices involved. This difference also was reflected in the use of the e-DAP at school (Figure 3-7), which also provides evidence that the workplace-taken pictures could easily pass the boundary of the workplace to enter the school classroom and become learning material.

At the same time, however, not everything was immediately working as expected. Both in the parallel experience with bakers and this one with chefs, really involving the in-company trainers in giving explicit feedback was not so easy. At least, this appeared to be the case. Our log files were still telling us that some trainers continued giving very little if no feedback at all (see Chapter 4 for parallel results with Realto, another platform, including learning documentation). We say 'apparently' as we cannot say much about the feedback. In fact, we provided an integrated feature for giving feedback, but we cannot exclude – and sometimes we had confirmation – that the trainers preferred to speak and give comments orally to their apprentices than to do it over the platform, even maybe in front of a computer showing the learner's e-DAP. Meeting in person is absolutely normal if not better, as some COVID-19-related lockdown experiences confirmed for us.

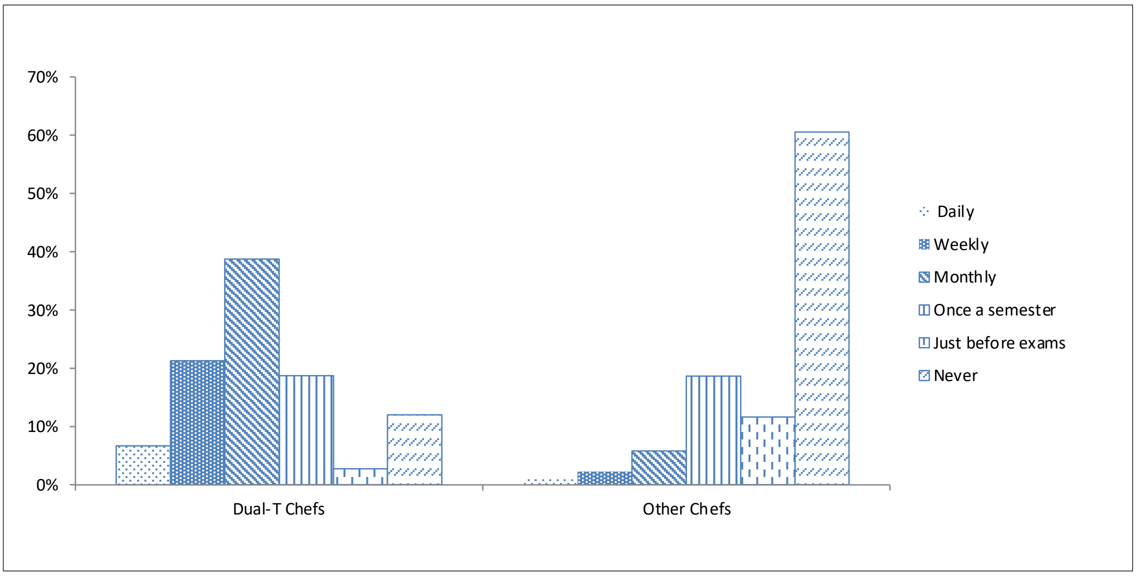


Figure 3-6 · Perceived potential of the DAP as a way to fill the gap between learning locations in various professions. With the chefs, we also contrasted those who had used e-Dap (Chefs_DualT) from those who had not (Chefs_Other).

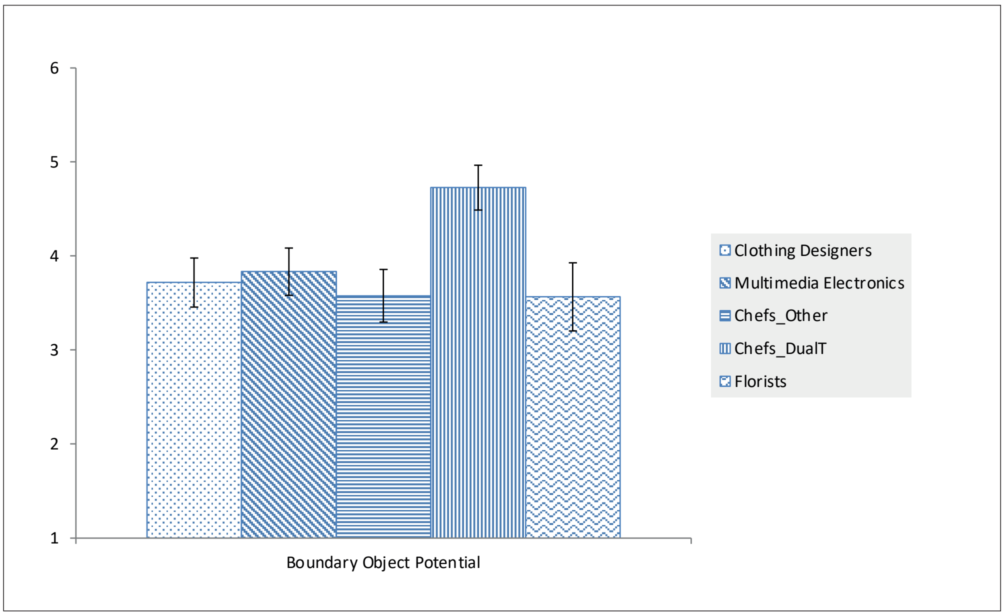


Figure 3-7 · Frequency of use of the learning documentation at school by apprentice chefs, contrasting those using the e-Dap (left) and those using a more traditional format (right).

Additional confirmation came in 2020 from a shorter questionnaire we submitted to the e-DAP users and to a control group made up of apprentices who had never been involved in Dual-T. We had questions concerning the 'existing connectivity' perceived by apprentices, taking, for example, the form of the teacher at school requiring learners to bring examples from their professional practice or referring to specific workplace situations. Once more, the comparison between the two groups showed that there was a significant difference in perceived connectivity occurring in their curriculum between people using the e-DAP and the control group.

However, this was distressful for Christian, who in May and November 2019 designed short workshops, where he invited the in-company trainers to remind them how to use the e-DAP and to emphasise to them the added values of using it with apprentices. Figure 3-8 (left) shows the number of feedback requests sent from 2014 by all apprentices populating the platform (in red) and the related answers they received by the in-company trainers (in aquamarine). The impact of Christian's intervention is visible when you contrast what was happening before (2014-2018) and after his intervention (2019-2020). At the same time, the time that passed between the request and the answer decreased significantly (Figure 3-8, right). Sometimes you just need a bit of push to increase your agency.

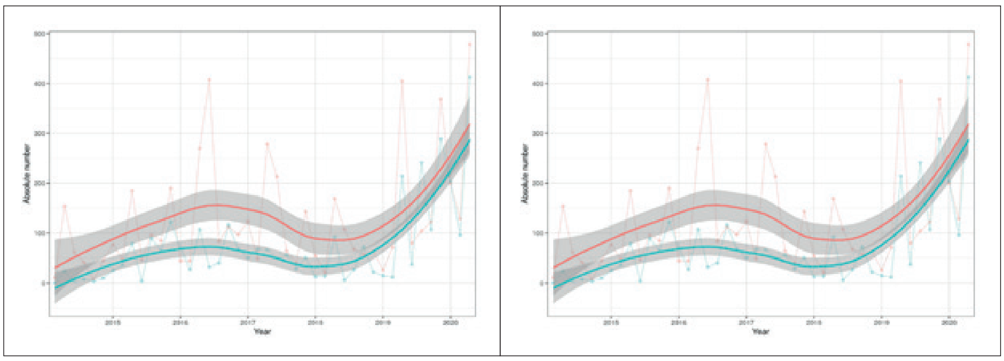


Figure 3-8 · Left: Number of apprentices' feedback requests (in red) and number of replies from trainers (in aquamarine). Note the rise in both metrics starting in 2019, which is when the workshops with in-company trainers were first offered. Right: Amount of time in days between a feedback request and response. Note the decrease beginning in 2019.

But we also have to state here that the boundary crossing consequences of the platform did not stop here. Other boundaries were crossed. For example, some time after the introduction of the platform, the cantonal inspectors in charge of visiting apprentices in the workplace to check that the training was proceeding well asked us to give them access to the e-DAP too. In their previous visits – due to the above-mentioned situation – it had been difficult for them to 'prepare' the visit in advance, and sometimes they also had problems accessing the paper-based DAP on-site. Nowadays it is common practice for them to look at the e-DAP before visiting, so that they can plan the meeting. Also, boundaries across professions crumbled so that, one year ago, the section of the school dealing with food and services (five different professions) adopted the e-DAP. This is also a story about networking (see Chapter 4), as the collaboration with both the vocational school management team and the cantonal office responsible for this vocational sector was nurtured from the beginning of the project to ensure its realisation and optimal operation. Progressively, having seen the result of the pilot interventions, both the school principal and the canton endorsed the widening of the experience to all the chef classes in the school. The negotiations with the national association to scale up the experience at the national level have on the other hand been only half effective: The national association (Hotel & Gastro Union) was supportive of the project and funded an upgrade of the platform, which allowed us to include many further options. A video clip promoting the project was shown in October at the general assembly and can be seen in German at http://youtu.be/M0U0qz9AjqY. But at the same time, it was only possible to have the e-DAP used in two other cantons. Anyway, we are not a sales company.

So what?

Working with bakers or chefs has been a really motivating story. We demonstrated that **collecting** experiences through mobile devices used in the workplace is possible and is, in general, well-accepted by the company bosses. Some of them even daydreamed about what it would have been like to have this solution at their disposal when they were apprentices. We can also demonstrate that getting apprentices to **reflect**, and even **write** down their thoughts – a not always well-accepted technology by hands-on people like apprentices – is possible too, and that this gives wonderful results on **practice** performance.

In the case of the bakers and chocolate makers, the change was only a change in technology, not a change in practice. Here, the professional association decided rather quickly to adopt the proposed solution and to generalise its use nationwide.

With Nicola and the chefs' branch, the change he introduced was not only technological, it also included a change in pedagogical practice; **sharing** experiences from different workplaces and **exploiting** them in the classroom proved possible too and highly effective for learning. But asking them to make a change in practice, even in culture, requires time and patience, especially since it needs the approval and involvement of different stakeholders beyond their respective current sphere of action.

Appendix

LJ-based Scenarios					
	M_{exp} (SD_{exp})	**M_{ctrl} (SD_{ctrl})**	**t-test**		
Cooking method 1	5.16 (1.68)	3.31 (2.57)	t(24.960)=2.461	p=.021	r= 0.44
Cooking method 2	5.12 (1.50)	3.63 (2.16)	t(26.549)=2.297	p=.030	r= 0.41
Cooking method 3	6.23 (2.09)	4.33 (1.81)	t(29)=2.698	p=.012	r= 0.45
Cooking method 4	5.07 (1.91)	5.35 (1.97)	t(30)=-.417	p>.05.	-
LJ-based Scenarios					
Cooking method 5	7.29 (2.62)	3.56 (2.74)	t(24)=3.410	p=.002	r=0.57
Cooking method 6	7.50 (2.90)	2.33 (2.18)	t(25)=4.710	p<.0001	r=0.69
Cooking method 7	7.00 (3.84)	5.20 (1.30)	t(22)=1.017	p>.05.	-
Cooking method 8	6.00 (2.81)	5.17 (1.47)	t(22)=.689	p>.05.	-

Table 3-1 · The difference in the number of metacognitive elements cited in the learning journal entries (experimental versus control group).

Session #	**# of questions (specific/total)**	**t-test**			**Experim. Group M (SD)**	**Control Group M (SD)**
General test on fish	12/14	t(34)= -2.420	p = .021	r = 0.38	3.19 (.32)	2.89 (.43)
Test on beef	3/17	t(37)= -2.308	p = .027	r = 0.35	5.62 (1.44)	4.58 (1.35)
Test on veal, pork and lamb	2/25	t(37)= -1.834	p = .075	r = 0.29	2.33 (.66)	1.97 (.55)
General test on meat	6/14	t(35)= -2.587	p = .014	r = 0.40	5.33 (1.06)	4.48 (.90)

Table 3-2 · The difference in the learning test score (specific questions only) between the experimental and the control group.

Chapter 4
Sharing experience: The painters' story

Jean-Luc Gurtner, Alberto Cattaneo, Alessia Coppi

As mentioned in Chapters 2 and 3, apprentices often have a hard time linking what is being done at school with what they experience at work in the host company. Everything differs between these two contexts – the setting, the colleagues and the possibility versus impossibility of reaching out to more experienced persons to receive help or ask questions whenever needed (Resnick, 1987). Each location has its own agenda and programme. Nothing guarantees the matching of the content with the topic addressed since, with few exceptions, as in the very seasonal professions, each company may be working on a different topic at a given point in time. So, school information might come too early for some and too late for other apprentices of the same class. Can technology be of any help here? And how? We saw in Chapter 3 that technology offers the possibility to 'cross boundaries' and that its appropriate use can help teachers to give meaning to what is being worked on at school by linking it to what is experienced at work. The current chapter deals with the same issue but comes from the opposite direction, investigating if and under what conditions schools can provide help to apprentices in doing their work at the company and, hence, ease the job of VET trainers out there in the host companies. A story taken from the lessons given by a prominent teacher in the branch of painting illustrates this 'boundary crossing' scenario.

Connected partners but independent actors: the current state of togetherness in VET

The VET system in Switzerland is jointly administered and governed by three partners, attached respectively to the federal level (state secretary for education, research and innovation), to the cantonal level (each state has its own office for VET) and to the various professional associations (Figure 4-1). Each partner has the triple mission of watching, controlling and organising given aspects of the system and none of them has the right or the power to change anything within it without the agreement of the other two partners. Because of the complexity and cost of the entire system, and because of the diversity of the needs of each professional association, but also to allow the diverse branches to regularly adapt their training plans to the evolution of the labour market, the three partners have to meet quite frequently and negotiate through diverse delegates and numerous committees. Together, they promote new or updated regulations, adapt ordinances, but also decide and attribute the financial resources to the various bodies in charge of conducting the real training in the various locations – mainly VET schools and branch course centres. At that level, partners work together quite well and regularly insist on the importance of creating and maintaining good coordination between the actors contributing to apprentices' training, whatever training locations they are based in.

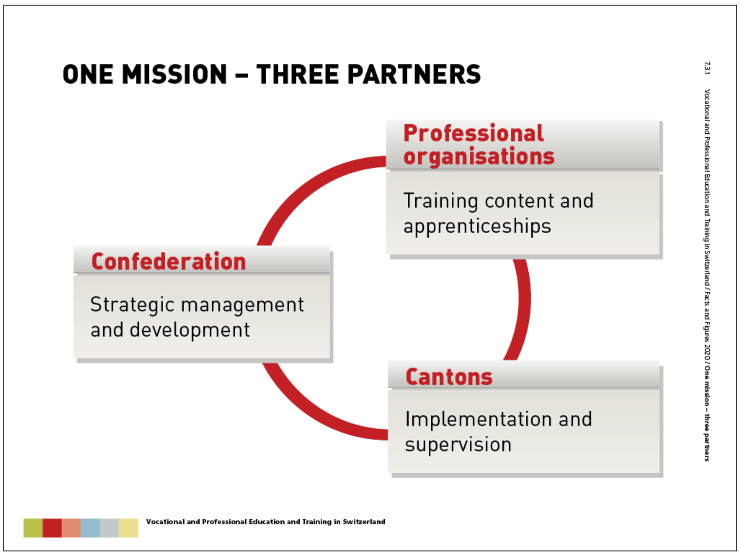


Figure 4-1 • The three partners supporting VET in Switzerland and their respective missions. Source: SBFI.

At the lower level, however, that of the actors contributing to the training on a regular basis – the host company, the vocational school, as well as the branch courses and centres (see Figure 4-2) – collaboration is rather exceptional and corresponds to diverse and varied conceptions of connectivity (Sappa & Aprea, 2014).

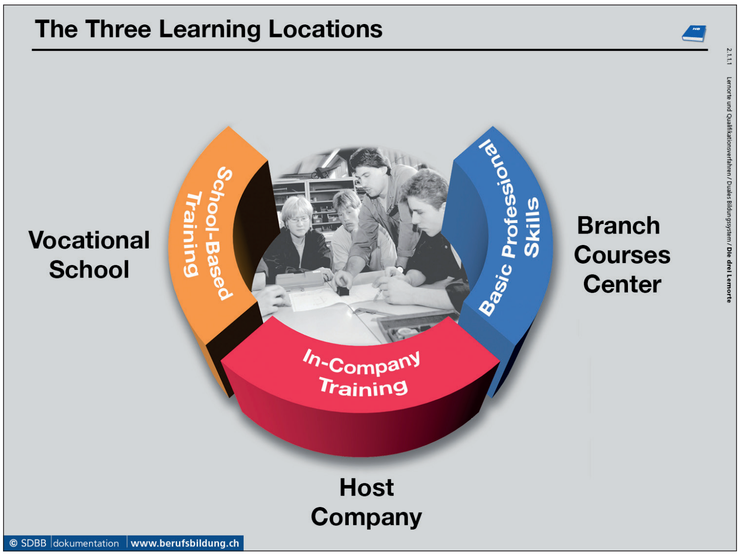


Figure 4-2 • The three actors contributing to VET in Switzerland (in black) and their domains of contribution (in white within the coloured shapes). Source: SDBB

It surely has not gone unnoticed to the reader that in the figure presenting the actual contributors to VET (Figure 4-2), neither the domains nor the institutions are linked in contrast to the partners presented in Figure 4-1.

It has been shown that the contacts between school teachers and company trainers mainly take place when a problem occurs, such as the misbehaviour of an apprentice (35% of the contacts between school teachers and VET trainers) or important learning difficulties (39%), while common projects (4%) or teaching material exchange (1%), for instance, were almost never mentioned as a reason for contacting another training actor during the period of the learning locations separation (Peter, 2014). Moreover, such contacts mostly pass through the school administration, not directly from teachers to trainers or vice versa.

Even less frequent, not to say almost non-existent, were contacts with branch course instructors, be they from teachers at school or a trainer in a company (Peter, 2014). Introduced into the VET system at the turn of the century only, and mainly performed in a third location set up and held by the professional associations, the branch courses are defined in the official texts as a complement to both the practical training in the companies and the knowledge acquisition done at school, and as a way to consolidate the basics of the profession. Such a definition is somewhat ambiguous, as we have been told many times in the other two locations: while some take this definition as an indication that intercompany courses are only secondary, others wonder whether their introduction could be a sign that professional associations have come to consider that the other two locations have failed to bring the necessary instruction to apprentices in the domain. As a recent report of the Ministry of Education of the canton of Zürich puts it, this could lead to 'frictions in the delimitation of the respective content to be transmitted' (Zürich, B. K., 2018, p. 99). Moreover, the timing and financial issues do not help mutual confidence and trust; for instance, apprentices' attendance at the branch courses at a given moment in the semester is compulsory, whatever the pressure at the company or the school is. Host companies contribute to the financing of the branch courses directly, but also indirectly through their membership fees to the professional association and because they have to ensure that the apprentices' salaries are paid even when they are attending such branch courses and are, therefore, not being productive for the company. On top of that, branch course instructors may be less experienced professionals than the host company trainers or former colleagues who have ceased running a company themselves. Conversely, professional associations often complain that VET schools do not give them enough spare time to run the branch courses with minimal interference in the school exams or their preparation, or during the holiday periods (Zürich, 2018). All of these conflicting interests tend to introduce mistrust, defiance and jealousy between the different actors, as we sometimes heard during our regular visits to the companies, the VET schools and the professional centres.

Vertically, the network around each actor is not much tighter; once they have received the authorisation from their canton to serve as a host company, enterprises are allowed to select whom they want as apprentices and are free to organise the training programme as they wish. The training plan has been defined by the professional association in terms of the competencies to be acquired in the workplace, but not in terms of timing – when to work on the acquisition of what competence – or in terms of importance – how much time apprentices should be given for acquiring what competence. Membership in a professional association is not mandatory and many professionals consider it useless. In most companies, the apprentices are mainly mentored very closely by the collaborator they work with because they share the same office, the same machines or the same professional sector. Their actual bosses are generally sitting in another office or another sector of the enterprise, and sometimes there is minimal contact with that apprentice. Sometimes they have another background or even another profession, as is often the case, for instance, in the health or the food sectors. For instance, the actual boss of a salesperson in a typical bakery is generally the owner of the bakery, a baker actively working backstage, while the person accompanying the apprentice in the shop is the baker's wife.

In a typical VET school, teachers of the same speciality number generally between one and three depending on the profession. Their links with the school direction are quite loose. As very different occupations are grouped in the same section of the school, contacts with the head of each section – called a dean – are maintained at a minimal rate and are rather organisational, not pedagogical. This diversity of backgrounds of the actors as well as the complexity of the configuration further leads to most VET schools controlling teachers on administrative issues, but not on content or methods to be used in teaching. It is, therefore, not false to pretend that VET teachers are rather independent and that they like it to be so. None of these observations of course should be taken as a criticism of the system. They are only the result of repeated observations of the situation in most professions and most VET schools, a situation that has arisen due to the complexity of both the organisation of the labour market and of the dual (trial) training scheme.

Despite the high complexity of the network around each apprentice and the efforts invested by those organisations which administer the system (the partners) for a fruitful collaboration, the actors actually contributing to that network remain rather loosely interconnected and feel mainly independent from each other. Each one has their own agenda, priorities, programme and activities to propose to the apprentice, and even if the curricula clearly prescribe what should be taught and practised at school, in the branch courses or at work, collaboration is nowhere requested nor really expected. A study by Peter (2014) shows, for instance, that while the majority of in-company trainers welcome school activities requesting part of the job to be done in the enterprise, an equivalent majority of them consider that such activities should remain infrequent and require no time, attention or effort to be invested in by the in-company trainer. Apprentices are also ambivalent about such connections. If they generally consider what they are taught in the different locations as being highly disconnected, and welcome more connections in their programme, they are not sure they would appreciate their various 'trainers' having deeper exchanges about their performance and attitudes in the different learning locations. This has not changed much from a study conducted in 2011 where apprentices clearly identified themselves as 'hands-on' persons (Taylor & Freeman, 2011), and where a rationale oriented towards the productivity typical of the business-driven location prevails against the learning-oriented rationale characterising the school (Illeris, 2011). In a survey we conducted within the project, for instance, we asked the stakeholders about the possibility of showing the teachers at school the apprentices' Learning and Performance Documentation, a requirement that must be completed and corrected in the company. We saw that apprentices were significantly less in favour of giving access to it to their teachers at school than were the teachers themselves or their in-company trainers. Teachers at school declared themselves happy to have a look at this documentation to see what the apprentices were doing in their respective enterprises, but were less willing than any other stakeholders to be involved in commenting or correcting apprentices' entries in these documents (Caruso et al., 2020). To make a long story short, it is a bit like if each trainer wants to see what is done in the other locations but is not ready to invest the time and effort beyond their actual responsibilities, simply to facilitate the task of another trainer or to make it more fruitful, what we sometimes refer to as a 'peep in but not chip in' principle (Gurtner, 2021). In our view, this strong 'independence' of the various actors leaves the difficult task to the apprentices to bundle together what they learn in the different learning locations, a job that might well be a real challenge, as we already know from the vast literature contrasting informal and formal learning. We, therefore, decided to explore how learning technologies could boost the collaboration between the various actors intervening in the VET training and so help apprentices to 'see' more clearly the connections between what they learn at school and in their enterprise. This collaboration, we thought, would be even easier to set up since, as we have seen in Chapter 1, most VET school teachers and intercompany trainers have formerly been or still are professionals.

Take advantage of technologies to foster collaboration among the various actors across learning locations

As already presented in Chapter 2, the Erfahrraum is a virtual space in which experiences made by an apprentice in one location, generally the workplace, can be decontextualised and transformed into a more abstract, elaborate and reflective form; it is also a space that teachers and in-company trainers can access without being physically there. But what is present in the platforms developed so far in the project (see Chapter 3), such as LearnDoc for bakers or e-Dap for cooks, has been inserted by an apprentice, with teachers and in-company trainers being offered the possibility to consult it and eventually to react to those traces, not to provide their own content or to trigger apprentices' reactions to their own input.

We, therefore, decided to design a new platform on which teachers and in-company trainers could upload content, not just the apprentices, that is, a platform that allows easy transmission from one location to the other of any content that a stakeholder wishes to make accessible to another of its users. The metaphor of a bridge immediately came to mind, with its double function of being a connector and short-cut between two locations. Based on previous experience, we knew that this could not be an open-air bridge, such as the Golden Gate or the Pont d'Avignon, since the content to be transferred along this bridge may sometimes be sensitive. Not all in-company trainers accept people from other companies being able to see the kind of work done in their own company; nor is every teacher ready to share their material with teachers from other schools. We then remembered that in other countries, such as Italy, well-known bridges often have walls and a roof, yet facilitate the transmission of goods from one location to another while, at the same time, preventing people all around from seeing the content actually transferred. This is especially the case for the Rialto, the well-known Venetian bridge. We, therefore, decided to name this new platform Realto, a name that is sufficiently similar to that of the well-known bridge without being totally identical to it. Moreover, the term 'Realto' implicitly makes reference to the 'real' experiences we wanted learning to start from, and it also attracts the reader's attention by the presence of an 'e', which is typical of any electronic environment.

As part of the family of the previously developed platforms, Realto still offers apprentices an easy way to upload material captured in the workplace (e.g. photos, films, notes), elaborate on it somehow and present it in various forms and degrees of reflection to the trainer at work or the teacher at school. These forms may range from simple posts to fully elaborated documents, such as learning documentation. Due to the sensitivity of some of that material (i.e. to keep it as a 'safe' bridge), accessibility to the platform had to be restricted in many ways, as with the previously developed platforms. Through a login and an invitation procedure, which makes sure that only the 'right' people can see the material uploaded, Realto also provides the option of manually setting and modifying the access to different sections. But privacy was obviously not enough to encourage teachers and in-company trainers to share information on the platform. In her doctoral thesis, Nicole Furlan (2017) saw, for instance, that feedback to apprentices' learning documentation by their in-company trainers was not more frequent with Realto than with a more traditional paper and pencil format (although this differed a bit in other experiences, such as the chefs' ones – see Chapter 3). Two other aspects were, however, more encouraging: the delay between the publication of a learning document on the platform and the reception of feedback was shortened with Realto, and the completeness of this feedback (assessed in number of words) was higher than when feedback was given via a pencil only.

If the absence of effect on the frequency of reactions as well as the effect on the speed of the reply is fully in line with what we already know from social network practices and other platforms (see Chapter 3 for similar results with the chefs' platform), the impact of Realto on the completeness of the feedback was more unexpected and encouraged us to keep and refine the system.

A *Notification* function was then added, allowing users to let those 'right' persons know that feedback was expected from their side. The first idea of such a function was an email or a message on the addressee's phone. But reactions to this idea were actually ambivalent, not everybody appreciated being alerted that way while, for others, it was a welcome reminder and a useful indicator of the work accomplished by their apprentice. In line with other social media, we decided to go for less intrusive versions of that notification function – in the form of a red flag being flashed in the addressee's to do list on the opening screen of Realto, completed or not by the name of the person requesting a reaction (see Figure 4-3) – and the possibility of the addressee deciding on the frequency they would accept receiving such notifications according to the type of reaction expected.

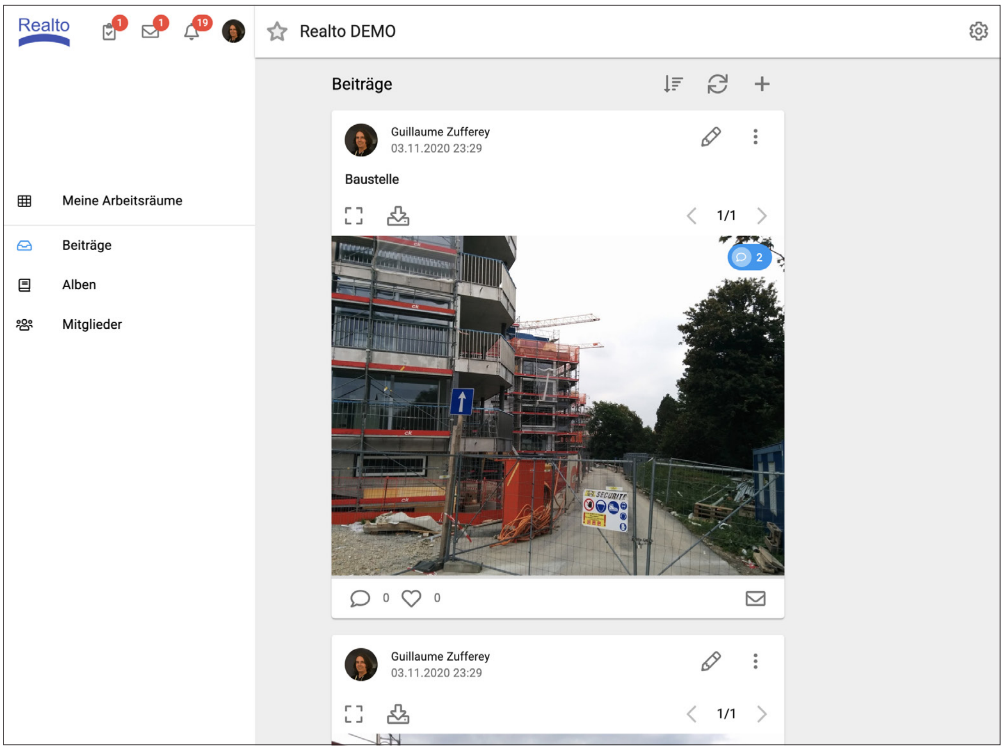


Figure 4-3 • Screenshot from Realto showing next to the Realto logo the to do list, with the red dots indicating the notifications received as well as who in the network actually sent it.

But the Erfahrraum does not foresee the possibility for the in-company trainers at the company to see what the apprentices have done or are currently doing at school. To make the exchanges go both ways – and not only through what the apprentices may say or carry over the bridge to the company – we decided to provide different solutions enabling the in-company trainers to be informed of – or even involved in – the work being done at school. To allow this to happen, we offered teachers the possibility of inserting directly on the platform, actually in the class workspaces, not only documents and photos, but also complete activities to be worked on by apprentices outside of the school physical environment. Our naïve expectations were that apprentices would then complete the school task in the workplace with their in-company trainers out there looking over each apprentice's shoulder, and so be regularly informed of what apprentices and teachers were currently working on in school. From an inquiry, we, however, learned that most apprentices actually access Realto from home more often than from the workplace, a general observation that varies a little bit from profession to profession and from workplace to workplace (Caruso et al., 2020).

Another idea was to have in-company trainers directly connected to the teachers through an invitation email to integrate them into the classroom workspace. This proved to be not such a good idea since it led to an avalanche of notifications that quickly submerged the pilot in-company trainers. The in-company trainers were not only notified about the activity of their own apprentices, but also by the activity of all the participants in that same class workspace – the teachers, apprentices and the related in-company trainers – an effect that led to most in-company trainers simply denying invitations and ignoring notifications. A possible solution to that problem, we thought, could be to filter the posts and to limit them to those concerning a given apprentice, but it soon proved impossible to separate these messages from those which, while not being specifically addressed to one apprentice, could be useful and relevant to that particular trainer. Thus, filtering information on that basis would have been either too restrictive or too open to remain sensible. To alleviate this risk, and to make the tool adaptable to the diverse sensibilities of its users, the notification functions of our platforms offer many options, so that they can be set according to each user's preferences, Our data also reveal that certain groups of users have invented original ways to get around such difficulties, proving their will to "close the loop" and open communication paths between teachers and in-company trainers even when "nothing goes wrong"(!); in some cases, we saw teachers giving the in-company trainers of their "common" apprentices access to their own folder of the tasks prepared for students; in other cases, we witnessed the creation by teachers of parallel workspaces in which they could pass information to the in-company trainers related to the work being done at school and welcome their reactions to them. Of course, these solutions might appear to be a restriction to the intended 'open' philosophy of the Realto platform, but at the same time they are simply the result of pragmatic decisions to keep in-company trainers regularly informed of what is being done at school. Such alternative communication paths also allow teachers to inform in-company trainers of any assistance they might wish for, in directing their 'common' apprentices towards relevant material, assisting them in completing activities or letting them experience at work a given skill, as is the case of the chefs' platform presented in Chapter 3. The example developed below in the case of painters shows that some teachers directly use the class workspace to alert in-company trainers of new regulations or developments they might not be aware of, for instance in the field of security at work, health prescriptions or new products developed by cutting-edge labs. Conversely, in-company trainers can also take advantage of such communication paths to ask teachers at school or instructors of branch courses to provide more explanations about a phenomenon, a principle or a technique that apprentices should better understand in order to be more effective at work.

Another way we found of boosting interactivity on the platform was by acting on the training scheme adopted to prepare the different stakeholders to using Realto. In a study conducted by Felder (Cattaneo et al., 2021), training the three stakeholders together (i.e. having teachers, apprentices and their in-company trainers jointly participating in the same training sessions) had a long-term impact on the apprentices' activity in the platform throughout the school year, while training them separately resulted in a regularly declining activity rate in terms of productivity. We suppose that being trained together gave the various actors the feeling of being involved in a team, which led them to act as reciprocal supports when the amount of motivation or the time available eventually decreased.

The importance of building a team as a way to increase learners' activity is also clearly visible in Figure 4-4. There, we contrasted the mean number of learning documents produced each month of a full school year by three groups of apprentices, based on the types of connections activated on Realto; we distinguished between those apprentices who had connections only with their teachers (star connections, invitation received from their teacher with host company trainer not involved), those who were invited to Realto by their host company trainers, but without their teachers participating (bi-lateral connections; this situation generally happened for those apprentices whose company trainers had reacted positively to an invitation by their professional association), and those who had open connections with both of them, with the teacher and the trainer also being directly connected (trilateral connections). Although the latter scheme took a bit more time to be established and become effective (see positions in September), this trilateral connection (solid line) clearly led to higher and more sustained productivity (measured in terms of the mean number of learning documents each learner posted every month) compared to the other two connection modes.

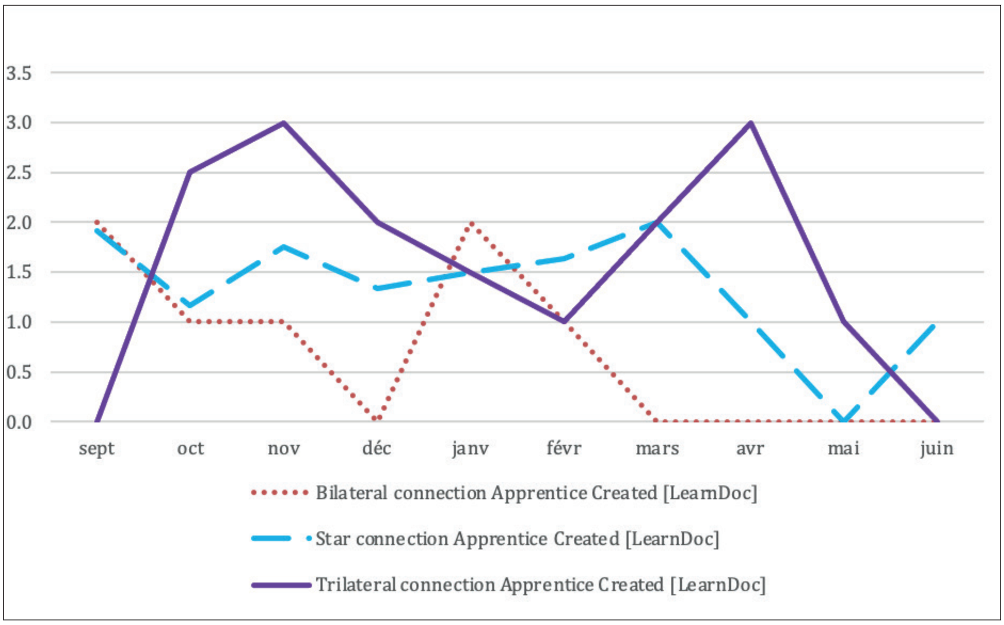


Figure 4-4 · Mean number of learning documentation posted by the apprentices each month in relation to the type of connections established in Realto.

How painters use Realto as a connecting tool between learning locations

In the paint branch, most companies work on customers' requests and work in private houses but also inside and outside larger buildings often still under construction. Security issues there have high importance and the domain called 'Security at work, health and environmental protection' is nowadays one of the four domains of competencies around which the learning plan is organised. Despite employees' security coming under the remit of the company they are under contract with, many enterprises in the branch struggle with this issue for different reasons. The number and the language complexity of the acts, ordinances and regulations dealing with the topic increase regularly and keeping track of these prescriptions is often out of reach for most VET trainers. Moreover, more than 95% of the companies in the branch have fewer than 20 employees, all of whom prefer to go out and paint rather than to attend courses on these new regulations. On top of that, it is well acknowledged that young people have a different appreciation of dangers and risks than more experienced ones (Breslin et al. 2007). VET trainers are, therefore, quite happy that VET schools and branch courses do their share of training apprentices on these issues.

Christoph Wüthrich, a teacher at the VET school in Wattwil, who uses Realto in his courses on a daily basis, has taken the opportunity to use Realto to teach security and prevention to the in-training painters. To enrich his teaching of the acts, regulations and prescriptions with examples taken from the field, he asks apprentices to provide photos from various work situations and discusses these with them, focusing on the dangers and risks they contain and contrasting them with the various prescriptions, acts and regulations on security issues at work set at the federal or the cantonal level (in pink on Figure 4-5). He also complements these discussions with a variety of brochures and booklets provided by the professional association or other institutions, summarising the measures appropriate to handling typical risky situations safely or presenting the best practice in such situations (in blue in Figure 4-5). Finally, he puts the PowerPoint presentations he used in class on the platform (in dark red in Figure 4-5). According to Wüthrich, the teacher's presentations, as well as the booklets and leaflets he inserts on the platform, are meant for the apprentices but also, interestingly, for their host company trainers, so that they become aware of what the apprentices were presented with at school and, at the same time, can learn about any new act, regulation or prescription introduced by the political authorities on security at work or risk prevention issues. These are changes which professionals often have a hard time getting to know about and adopting in their day-to-day practice.

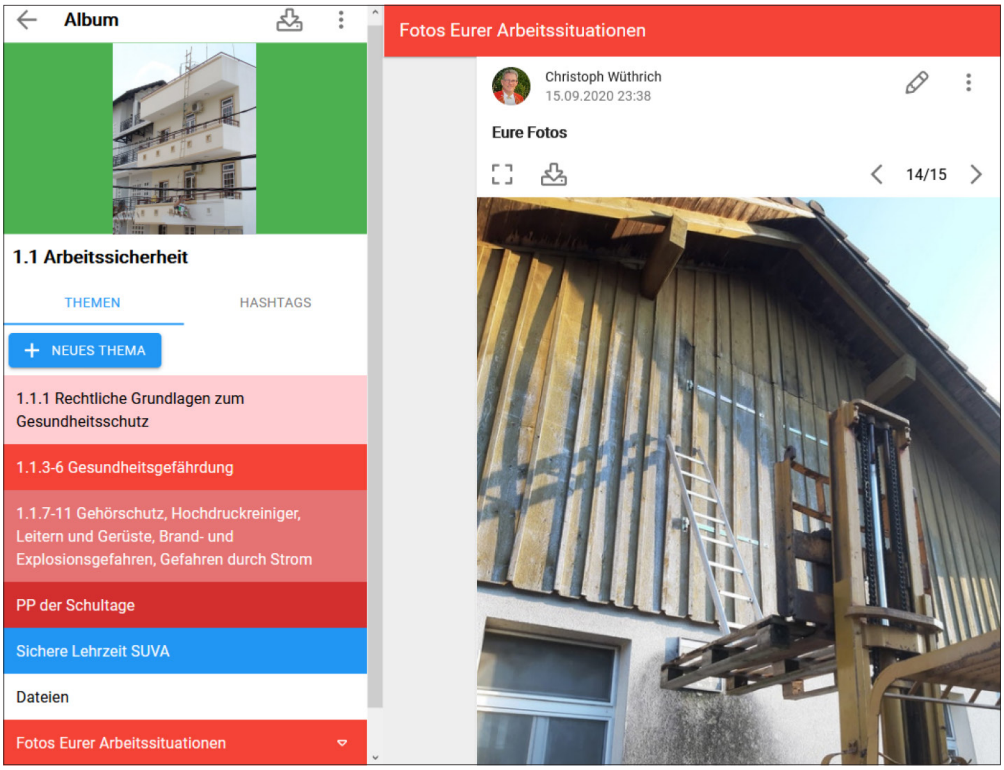


Figure 4-5 • A screenshot of an activity conducted in class by Christoph Wüthrich around the topic of work security.

Activities like this one give apprentices a better feel for the risks and dangers one may face in their professional activities, a competence that is greatly appreciated by their VET trainers and host company owners. Some of them even consult their apprentices on what to do in delicate situations or nominate them as 'company security experts' in case of potential controls conducted by work inspectors.

So what?

Realto's ultimate goal is to offer the VET actors an easy way to stay regularly connected and to learn, possibly in real-time, about the efforts being conducted in the other locations to train their 'common' apprentices. This is challenging since it requires the involvement and commitment of many people, with different priorities and needs. Christoph Wüthrich's example shows that collaboration is possible and even valued when the partners understand and appreciate the help another actor can bring, not only to the learner's training but also to themselves in performing their own activities.

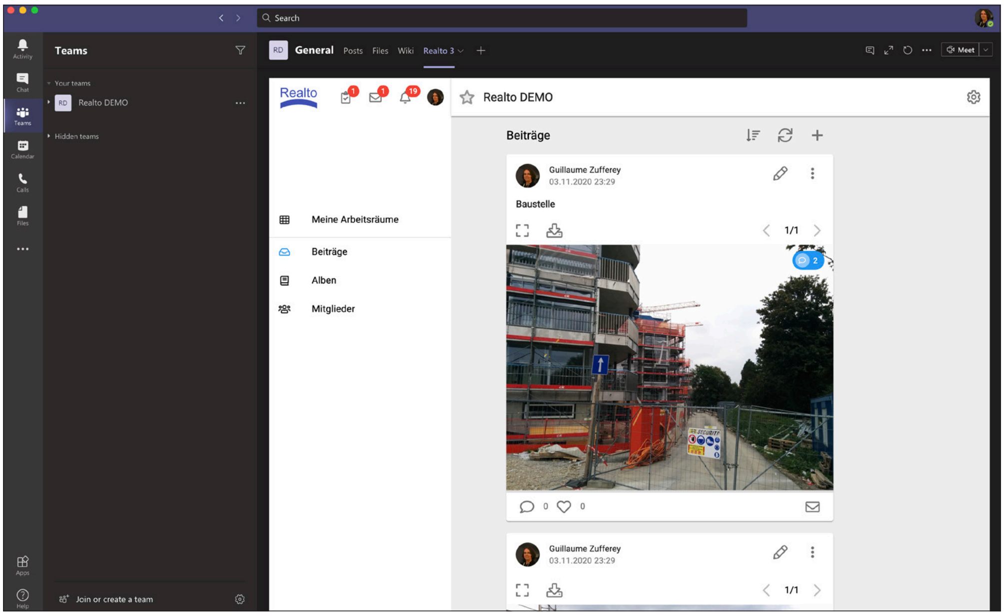


Figure 4-6 • Screenshot of an activity integrating Realto (in white) with an MS Teams session (in black). A simple button added to MS Teams (Realto 3, centre top of the screen) allows one to pass easily from MS Teams to Realto.

Unlike e-Dap (Chapter 3), which was tailored to the needs of a specific profession, Realto is easily transferable to the needs of a wide range of professions. It is currently regularly used in 10 different professions by roughly 1,500 apprentices, 250 teachers and 250 professionals across the country. Moreover, the issues of security and risk prevention are crucial topics in many professions, and the pioneering work done by Wüthrich could serve as a basis for many training programmes and professionals in various fields. Chapter 5 presents another development of Realto, aiming at supporting yet another common widely used didactical practice, namely the annotation of pictures and videos whether taken from the workplace or from sources such as magazines or the Internet to direct apprentices' attention and make them adopt a professional vision or learn the codes, marks and symbols that constitute any profession's visual language.

With respect to sharing information and making multilateral contributions accessible beyond the borders, Realto is, of course, not unique and could easily be replaced by other communication platforms, such as MS Teams or Moodle and the like. Recently, VET schools began adopting MS Teams on a wide basis. Because of this, it was decided to make direct access to Realto possible through MS Teams directly (Figure 4-6). To support teachers who might be more comfortable working with other technologies, we have created a website for VET teachers called eduscenarios.ch. The website contains 14 step-by-step descriptions of Erfahrraum-compliant learning activities that teachers can adapt for their students, along with advice on how to use a variety of different technologies (including MS Teams and Realto) to support those activities. Our goal is to provide resources that make it easy for teachers to bridge the gaps between the workplace and the school by implementing Erfahrraum-compliant activities in their classrooms.

Chapter 5

Annotating experience: The clothing designers' story and beyond

Alberto Cattaneo, Jean-Luc Gurtner, Valentina Caruso, Alessia Coppi

The previous chapters demonstrate the importance of images in various professions' communication systems, as well as their potential for the training of newcomers in the field. But as we heard from various professions, VET teachers are not only happy to work 'with' images, they also like to work 'on' images. This chapter explores how learning technologies can help them go further in that direction and how teachers of different professions can make use of picture annotations, labelling or contrasting to foster apprentices' specific professional visions.

We know how important visual information is for human beings. Also, from a psychophysiological point of view, on average, about 50% of the brain's resources are dedicated to constantly selecting, elaborating on and interpreting visual information. On top of that, we all live in an image-based society. We are surrounded by pictures, whether in a static or a dynamic format. Many social networks specialise in picture sharing – Flickr, Picasa Pinterest, Instagram. Platforms such as YouTube constantly appear on the podium of the most accessed Internet website and most of our daily communication tools, WhatsApp, for example, allow us to modify and interact with pictures.

In the previous chapters, we observed how teachers used these kinds of pictures with chefs, bakers and painters and discussed them with their apprentices, prompting them to look for similarities and differences in workplace practices and to compare processes and detect products' qualities and defaults. We often noticed that an image that might look insignificant to a non-expert often included several interesting and meaningful details for a professional. Teachers can highlight these details to apprentices and draw their attention to them, so fostering a professional-specific way of looking at images.

Also, we saw that in several cases, teachers chose to do further work on images, for example, pasting to-be-commented pictures into a PowerPoint presentation in order to add labels, markers, notes or other indications, and building a sort of visual summary of technical information to be learnt. To speak the Erfahrraum language, we would say that in these cases, raw artefacts are 'augmented' through the addition of successive layers of information, for example, by focusing attention on relevant information or by integrating comments and analysis by community members, or by adding elements of theoretical knowledge to practical experiences as a result of a discussion orchestrated by the teacher.

These two general considerations brought us to deepen two different topics, one related to how observation takes place (professional vision) and the other related to how observation skills can be improved (annotation).

Observation as a professional practice

In 1994, Charles Goodwin published a paper simply entitled 'professional vision'. It referred to how professionals embody specific visual practices, depending on their vocation. Professional vision refers to 'socially organised ways of seeing and understanding events that are answerable to the distinctive interest of a particular group' (Goodwin, 1994, p. 606). In other words, visual practices – including actions such as coding, highlighting and producing practice-related visual materials – are context-bound and profession-specific. Valentina Caruso and Alessia Coppi, two collaborators who developed PhDs on this topic as part of the Dual-T project, documented these definitions in their thesis (Caruso, 2017; Coppi, 2021). They adopted Goodwin's definition to investigate how observation takes place within a professional community and took into account a huge literature applying a similar concept to teacher training. In this case, scholars spoke about ‘noticing’ (e.g. Seidel & Stürmer, 2014; Sherin et al., 2011; Stürmer, et al., 2013; van Es et al., 2017), meaning a two-sided competence, combining both the capacity to identify and discern the relevant details of an observed phenomenon by effectively directing and focusing one’s attention on it, and the capacity to draw connections between the elements observed and one’s knowledge so to be able to reason about what is observed in meaningful ways and accordingly decide how to react. We are insisting on these premises because of their link to our pedagogical model – and to our related research activities. Indeed, what we recognise here is a kind of tripartite activity, as we need an objective referent (collect: visualisation), we need to identify it explicitly (prepare: perception and description), and then we can infer an explanation and predictions (exploit: (cognitively and socially determined) reflection). We recognise these three elements in the examples we present in this chapter.

Let us start with our story. We will look at the case of clothing designers first and how and what they observe. Then we will look at the instructional means we used to teach clothing design apprentices to observe in compliance with our model.

How does the observation of experts and novices differ in VET?

When studying observation, several scholars have investigated whether experts and novices proceed in the same way when practising their profession. In recent years, this has been further empowered by the availability of eye-tracking technologies and techniques, allowing one to follow and track the gaze of a subject. Several professional fields have benefited from these studies, which have always focused on white-collar professions. That is, little to no attention has been devoted to vocational education. This is quite inexplicable considering how observation skills are central to many craft and industrial professions. This was also confirmed for us by the analysis of several VET training plans. Our attention was initially focused on garment makers or clothing designers.

In the profession of fashion design, good observational skills are relevant, as these skills help fashion designers precisely analyse a piece of clothing, ultimately resulting in good product creation. When creating and reproducing new clothes, fashion designers must identify specific visual information, usually represented by a picture or by that specific technical drawing called ‘pattern’.
In the first study (Caruso et al., 2017), we asked a group of ten teachers and a group of 71 apprentices to tell us what relevant visual information they paid attention to when analysing and creating clothes. We considered teachers as expert professionals because, in this case, fashion design schools also act as companies, tailoring clothes for external customers, and because the involved teachers are still or have been professionals. Results show that clothing designers consider three main types of visual information when observing garments: 1) the details and patterns necessary for reproducing clothes; 2) the defects in manufacturing, quality and wearability; and 3) the characteristics of the customer’s body. However, the extent to which novices and experts pay attention these three categories differs between the two groups. Before commenting on this point, let us add a second element: to measure a possible difference between the two groups, we also administered them a test. We showed the participants a set of ten pictures, including several categories of defects, and asked them to fill in a table, identifying for each picture 1) the categories of defects identified; 2) the defects description; and 3) the possible corrections. The analysis revealed that not only did significant differences exist between teachers and learners when looking at pictures of garments, but also among the learners, depending on the school year they were in: the more advanced tended to behave more like experts do (See tables 5-1 and 5-2 in the Appendix for statistical data).

The full picture is represented in Figure 5-1. In looking at profession-related visual information, the teachers concentrated on identifying the details and patterns useful for making clothes, mentally disassembling the image, and used their prior knowledge to make sense of what they observed and to predict the necessary work procedure. On the other hand, the learners concentrated on identifying the potential defects in the final clothes; their limited technical knowledge led them to focus mostly on easily noticeable elements, such as defects, hindering them from identifying other more relevant information (e.g. different types of patterns) or from connecting this information with the specific actions required in practice to produce a garment.

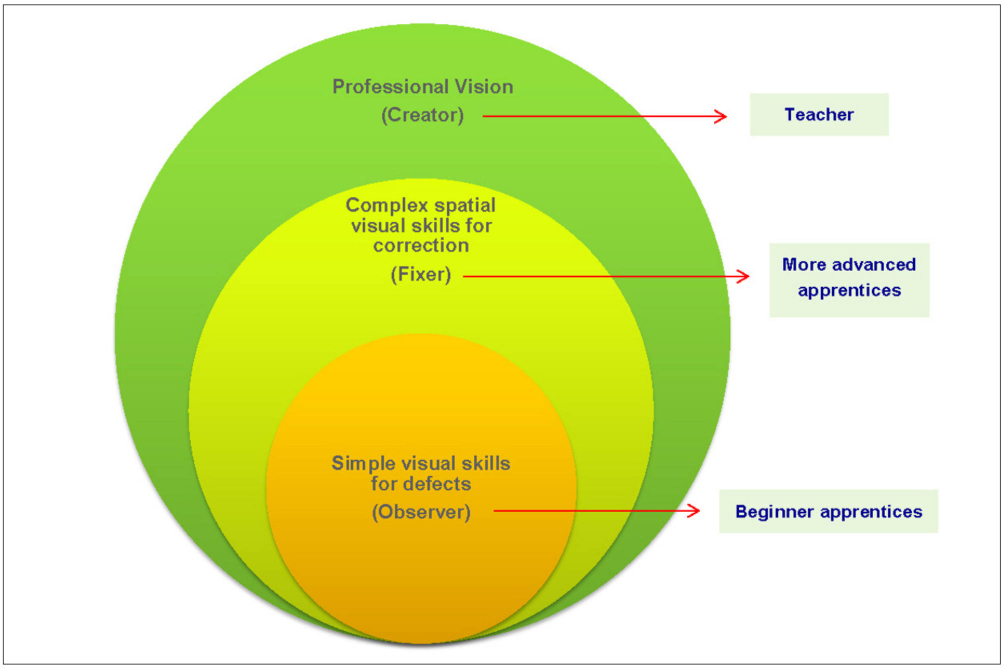


Figure 5-1 · How observation evolves among fashion designers

Observing clothes professionally is a holistic process that involves complex cognitive skills; beginners can only spot defects but not see their origin. As they progress in their training, however, they start reflecting on corrections to fix the problems.

Additionally, a crucial component of a professional vision for clothing designers involves the visual-spatial skill of mentally transforming a three-dimensional shape (i.e. the garment) into a two-dimensional image (i.e. a pattern), and vice versa. This is an even more specific skill distinguishing experts from novices.

How best to develop observation skills?

Although it is a clear objective of the training, no clear procedure is defined either in the clothing designers' curriculum or in that of other VET professions to make apprentices acquire these skills. Teachers, therefore, tend to develop their own material and strategy to try and make this happen. We discussed this further with some of them, with the idea of investigating how learning sciences and technologies could help increase the potential of their strategy and material to develop professional vision among apprentices. The next three examples illustrate what this collaboration leads to.

The theoretical background for the activities came from the simple but powerful principles of the learning sciences, such as the signalling principle of the cognitive theory of multimedia learning by Mayer (2001, 2014) and the already mentioned principle related to contrasting cases by Bransford et al. (2000). As per the former, we conducted an experiment with an eye-tracking tool (Coppi et al., 2021) to assess the effectiveness of visual cues to focus the learners' attention on specific elements of a garment. Despite our more finely grained hypothesis not being completely confirmed and some difficulties related to the nature of the study – being realised in a real school context – a general effect of visual cues could be confirmed.

Example 1. Picture annotation with clothing designers

Continuing our collaboration with clothing designers, we started by observing some of the activities they did at school and identified two common practices related to the analysis of garments and their patterns. Together with Prisca Cattani, a teacher at the school of Viganello and with Sabrina Solari, a teacher at the school of Biasca, we further discussed how these activities could profit from technology and co-designed two scenarios supported by Realto, to be contrasted with the traditional ones (Figure 5-2).

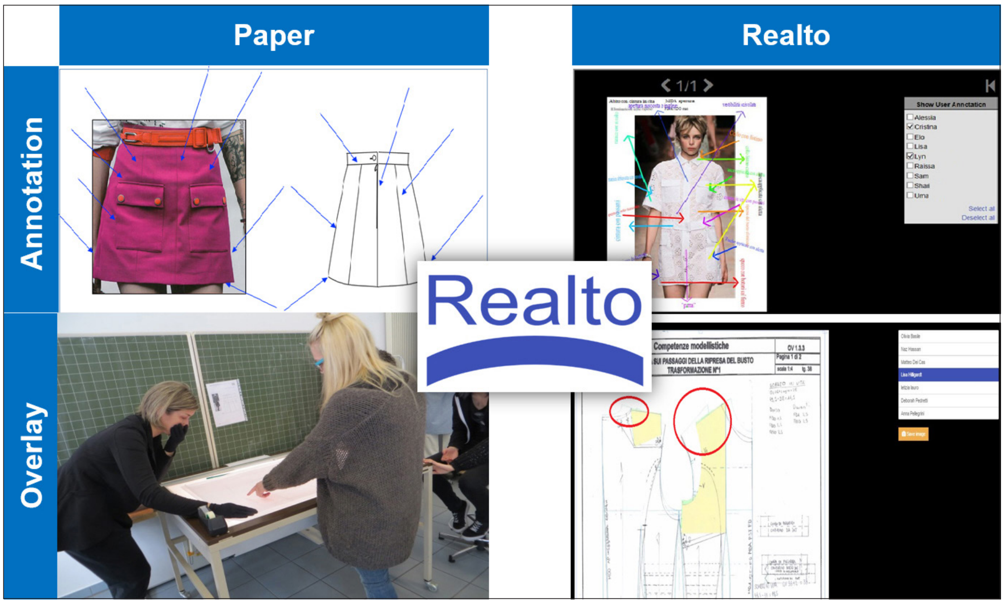


Figure 5-2 · Examples of activities focusing on strengthening observation skills of apprentice clothing designers, using Realto or paper only.

The first scenario concerned *overlaying patterns*. This was a scenario that Prisca and Sabrina were already using with paper and pencil. In this task, the students are asked adapt a skirt pattern to the needs of a hypothetical customer by working individually on it. The students' patterns are then printed on transparencies so they can be projected on a light table, around which the students can gather. The teacher's pattern is placed in the background, as a model, which allows students to identify and comment on mistakes, as well as to discuss how to correct them and how to be compliant with the customers' requests. In this version of the activity, two to three drawings can be superimposed, but not more. The teacher must constantly change the overlaid drawings as soon as new ideas are discussed. We decided to implement the same scenario using Realto. Students were given the same task but instead of turning their results over physically to the teacher, they submitted them online on Realto. Realto then automatically made the patterns semi-transparent, which allowed the teacher to display and remove them from what she projects to the entire class by simply clicking on the authors' names on the list of names that appears on the right of the screen (see Figure 5-2, bottom-right).

The second scenario focuses on cueing different parts of a piece of clothing (e.g. a skirt or trousers) and identifying the manufacturing defects detectable in the picture. In the paper-pencil condition, students are given two pictures of a garment (front and back) on paper and have first to identify each part of the garment using a coloured pencil to draw arrows and then must indicate possible manufacturing defects using arrows, circles and text. The teacher can project the annotated picture of a single student to the class using a beamer and again discuss with them, analysing the piece of clothing and guiding the students' observations. The paper-pencil solution restricts the teacher to showing one sheet of paper at a time, while the Realto-based solution allows for multiple annotated pictures to be superposed simultaneously on the class screen. The teacher can then display or hide any student's work to the whole class by ticking that student's name in the box on the right. The selected layers are displayed on top of each other so that the corresponding annotations possibly appear on the same (resulting) picture (Figure 5-2, top-right).

Both activities were implemented in seven different classes coming from two different schools. When possible, the activities were videotaped for analysis. Overall (for detail, see Caruso et al., 2017), the data showed that students made more spontaneous observations when using Realto than when using paper and pencil and that its use made students more actively and spontaneously engaged in the task than the use of paper and pencil (see tables 5-3 and 5-4 in the Appendix for the statistical results).

On top of these results, interviews with teachers and students allowed us to identify the perceived benefits of using Realto. For the teachers, these were: (1) encouraging creative teaching activities, which is generally not possible with other 'generic' technologies, (2) easily and more effectively supporting task correction, saving time, (3) focusing students' attention through cueing functions provided by the annotation tool, (4) engaging students in a variety of visual activities, and (5) improving the quality of the teaching materials.

The students, on their part, particularly appreciated the possibility of learning by sharing and seeing, getting immediate visual feedback, and being able to easily review their learning materials stored on the platform.

After these activities, clothing designers continued to use Realto independently, progressively integrating the use of the learning documentation (see Cattani, 2021; Basile, 2021 for additional learning activities implemented at school).

Example 2. Picture annotation with beauticians

A second experience took place within the profession of beauticians, for whom observation skills are very important too. Beauticians must learn how to perform skin analyses to identify most skin diseases and provide correct treatment, as well as to differentiate severe anomalies requiring a medical intervention from mild anomalies. Observing some of their lessons, we realised once again that some of the activities already conducted in normal classes could be enhanced by the use of Realto – through visual cues – again combining the use of annotations with image description (we previously spoke about description as the first step in a deep, reflective, analytical process). With respect to the activities promoted in the clothing designers' school, we were able to prepare a longer and more articulated treatment, and to better differentiate, in a learning scenario, annotations performed by the teacher as an instructional means, and annotations performed directly by the learners. For almost a whole semester, Claudia Berri and Luisa Broggini proposed activities for an intact class that served as our experimental group. Their lessons, run with Realto, were organised according to three main steps: 1) they presented pictures of skin anomalies uploaded in Realto to the students and directly annotated them (e.g., with circles and arrows) to explain how to identify specific anomalies and how to differentiate them from similar ones, 2) they asked the students to annotate a second set of images using Realto and to write a professional description for each image, 3) finally, they showed the class the students' annotations (see Figure 5-3) – also profiting from the Realto function that allows them to superimpose multiple images (see above) – and corrected them with the students.

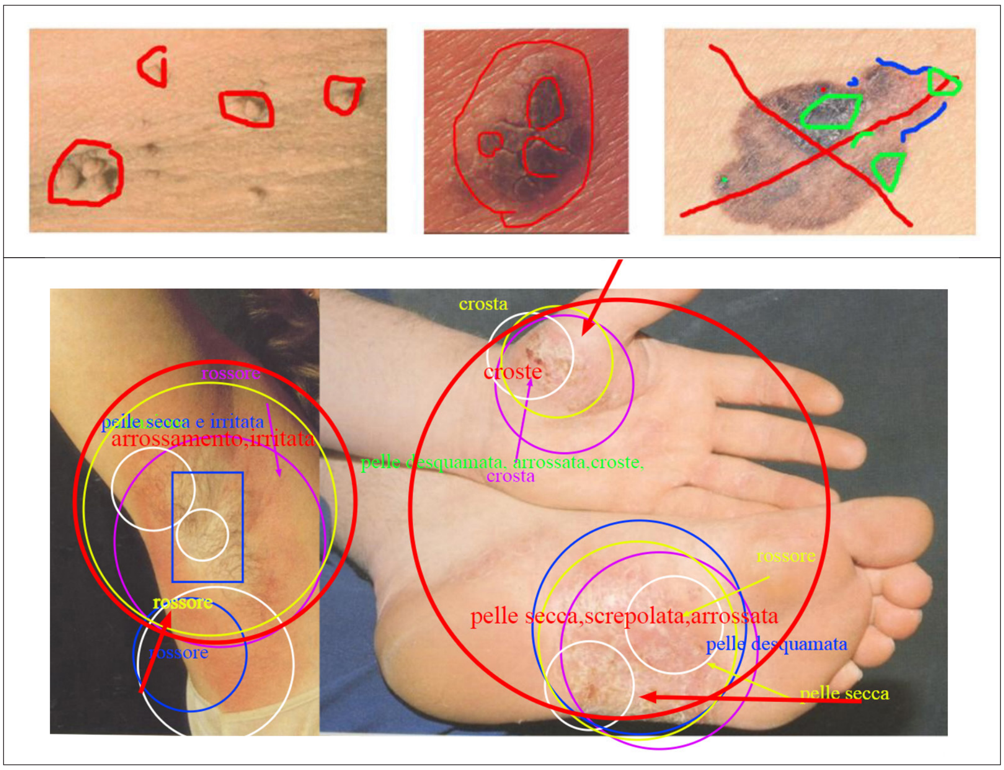


Figure 5-3 • Teachers' driven (above) and students' driven, overlapped annotations (below).

In contrast with the baseline group which only looked at pictures without annotations, we could see that the Realto-based approach was effective for sustaining the students in writing better and longer descriptions. Students also perceived the use of annotations and descriptions as a very powerful and useful tool for developing their observation skills, although not distinguishing between the effectiveness of the teacher's annotations and their own, self-managed ones (for more details, see Coppi & Cattaneo, 2021).

Example 3. Video annotation across professions

So far, we have only dealt with pictures. However, annotating can also be very fruitful when applied to videos, especially for reflecting on what the video displays in its amount of detail (Evi-Colombo et al., 2020).
We had already used video annotation with a dozen classes of office clerks in a previous phase of Dual-T (see Cattaneo & Boldrini, 2016). Classes were asked to simulate customer consultations and to video record (collect) them. Then the classes had to review their videos and track down what they considered to be bad consultation practices (exploitation through reflection). Thanks to the use of the video annotation tool which we provided them with, they could mark these passages directly on the film. The study aimed at showing the effectiveness of learning from errors compared to learning from the analysis of correct behaviours only. The results were successful, and other experiences like this one were promoted across different curricula.

If a more restrictive definition considers annotation as the result of a writing activity, a larger definition looks at video annotation as a process that enriches the video with additional materials, for example, through hyperlinks, to build a hypervideo (Cattaneo et al., 2018; Sauli et al., 2018). In this direction, we want to briefly mention two additional experiences, the first with student nurses, the second with chef apprentices. In the former case, nurses had to learn how to insert a urinary catheter. To collect their experiences, we video recorded their simulated practice with mannequins. In the latter case, some apprentices produced authentic videos in their workplaces, which were used as a basis for a classroom scenario. The videos dealt with the topic 'basic creams'. In both cases, students worked in groups, with the task of enriching the raw video and preparing a hypervideo containing all the important information to learn and concretely manage the procedure. We had a real control group with the nurses, which was not the case with the chefs. For all the specifications, see Evi-Colombo et al. (2021) and Gianetti (2021). The main finding to highlight here is the high effectiveness of this learning-by-design approach for learning.

Through our work across different fields, we found that picture annotation mainly has three functions in didactical situations: (a) *highlighting* a peculiarity of an object, a tool or a situation displayed by the picture (b) *labelling* it so as to increase the viewer's understanding and memorising of it, and (c) *educating the viewer's observation* so that they will learn the appropriate, profession-specific way to look at things.

Annotations to highlight particularities of a given situation or element **and direct the viewer's attention** to a specific point in the picture. We saw this function being used in particular by teachers who wanted to address the specific problems of a garment (clothing designers), to make learners pay attention to early signs of a given disease (beauticians and gardeners) or to a potential risk in a construction project (road builders). But we are convinced that this function could be used in many other vocational education situations. Teachers could choose to do the annotations on the pictures shown to the learners, or to ask the learners to annotate the picture provided, having an equivalent impact on the apprentices' learning and motivation (Coppi & Cattaneo, 2021).

Of course, one can use annotation to perform this function on any picture in any format; the picture does not need to be presented on a screen or the activity to be conducted on tech-based support. Any drawing or photo can serve as the basis of such an activity. You just have to copy it and distribute it to the learners. The teachers we worked with acknowledged, however, that the didactic potential of annotation was much richer and time- and cost-saving with technology than with paper and pencil. Technology allowed the annotated pictures sent by each student to be projected on the classroom screen, to be superimposed on top of each other, and contrast them more convincingly by selecting and deselecting the work of any student to emphasise their similarities or differences.

Annotation to ease understanding and stimulate remembering. This function is particularly evident in teachers' activities involving labelling the different parts of an object and the different components of a situation; this function is often used by the teachers either by introducing the labels themselves on a given picture or by asking the learners to add labels to a picture they are shown. This activity is considered by teachers as a profitable way to stimulate the acquisition of the technical vocabulary each profession has and which every professional acting within that field should master; but it also represents a good way to increase pattern recognition as well as the learner's technical thinking. Instead of names, teachers sometimes asked for numbers to be put onto these labels, so as to indicate in which order pieces need to be assembled (construction workers) or mounted (clothing designers). In a few cases, the labels had to receive arrows figuring the direction in which water will run (plumbers) or a pulley will rotate (car mechanics) for instance.

Here again, technology is not required to achieve this function of annotation. Playing it on technological supports extends, however, the potential of such activities, teachers acknowledged, by allowing, for instance, the object presented in the picture to rotate on the screen, with the labels moving accordingly or by allowing annotation of an evolving situation displayed on video. When the task consists of predicting which direction a flow will run or a pulley will rotate, technology again beats paper by allowing students to receive direct feedback on the validity of their prediction through animation or by letting the video run.

Annotation to educate observation (in a profession-specific way). In a sense, this third function of picture annotation is the final aim the other two functions tend to move towards. We learned that using pictures finally impacts learners' observation competence, and turns it into a professional vision, that is, it progressively bends beginners' rather naïve way to look at things into what professionals do when facing a picture or an object in their professional activity. Skin problems have a tendency to appear most frequently at certain places on a human face or body. But looking only at those places is no guarantee that no dangerous skin problem is developing. Professional clothing designers also well know that where a default becomes apparent, in the 'fall' of a dress or of a pair of pants, may not represent the origin of the problem. Being able to determine exactly how the garment has been realised, or the causes of a specific disease, clearly help the professional to direct their observation, not only at the critical points, but in conducting a more thorough, in-depth look at the entire garment, at the whole body of the patient.

So what?

This part of the Dual-T project confirmed that observation can be shaped and moulded so as to become more professional and that picture annotation, especially when supported by adequate learning technologies as the ones Realto provides, can make a decisive contribution toward this goal in many professional domains.

Of course, novices could probably learn to reshape their naïve observation by looking at many photos, with or without the annotations of a professional. Using technologies again here proved more motivating and more efficient than just handing over photos. Enabling learners to regularly contrast their own vision with that of the teacher or their classmates, to easily zoom in on specific aspects of the picture or zoom out and access a more general image of the clothing or the client's body shape proved to be well appreciated, both by the teachers and the students, as well as being a powerful didactical tool to transmit and establish among learners a professional vision in their respective field.

As the acquisition of a professional vision is a critical skill to master in many professions and industries, developing tools that enrich annotation-based didactical scenarios is certainly a direction to consider deeply in the reflection on the use of learning technologies in VET.

Appendix

			95% CI		
Comparisons	**Total Defect Mean Difference**	**SE**	**LL**	**UL**	**Hedges' g**
First-year vs Second-year	-.32*	.11	-.61	-.05	-0.52
First-year vs Third-year	-.03	.13	-.35	.30	-0.04
Second-year vs Third-year	-.31	.14	-.05	.66	0.53
First-year vs Teacher	-3.18*	.23	-3.8	-2.57	-4.48
Second-year vs Teacher	-2.87*	.23	-3.49	-2.22	-3.31
Third-year vs Teacher	-3.17*	.25	-3.82	-2.5	-4.2

* $p < 0.05$

Table 5-1 • Bonferroni Comparisons of defects (z-scores) identified by the participants.

			95% CI		
Comparisons	**Total Defect Mean Difference**	**SE**	**LL**	**UL**	**Hedges' g**
First-year vs Second-year	-.19*	.08	-.38	-.01	-0.52
First-year vs Third-year	-.34*	.08	-.55	-.13	-0.91
Second-year vs Third-year	-.15	.09	-.38	.08	-0.38
First-year vs Teacher	-3.69*	.17	-4.13	-3.23	-6.8
Second-year vs Teacher	-3.48*	.18	-3.95	-3.01	-5.42
Third-year vs Teacher	-3.35*	.18	-3.83	-2.86	-4.52

* $p < 0.05$

Table 5-2 • Bonferroni comparisons of corrections (z-scores) as suggested by the participants.

Item	Condition	Frequency	Mean duration (seconds)	SD	t	df	Cohen's d	Total duration (seconds)
Student's Interjection	Paper Tech	25 23	4.81 6.29	4.08 4.95	-1.13	46	-0.33	120.35 144.59
Spontaneous Observation	Paper Tech	28 40	2.89 13.96	1.50 12.05	-4.82*	66	-1.28	81.01 558.35
Induced Observation	Paper Tech	47 21	2.80 7.87	1.58 5.48	-5.86*	66	-1.25	131.79 165.32
Teacher's Explanation	Paper Tech	38 30	13.22 8.37	9.47 5.44	2.49*	66	0.62	502.09 251.06

Table 5-3 • Classroom events in paper- and Realto-based modes for the overlay scenario.

Item	Condition	Frequency	Mean duration (seconds)	SD	t	df	Cohen's d	Total duration (seconds)
Student's Interjection	Paper Tech	12 45	5.57 5.46	4.96 4.30	0.78	55	0.03	66.94 245.98
Spontaneous Observation	Paper Tech	3 9	6.00 6.79	4.26 3.65	-.312	10	-0.20	18.00 61.09
Induced Observation	Paper Tech	15 12	3.91 3.58	5.93 1.95	.181	25	0.08	58.55 42.96
Teacher's Explanation	Paper Tech	23 33	13.34 16.11	13.57 14.29	-.731*	54	-0.20	306.61 531.62

Table 5-4 • Classroom events in paper- and Realto-based modes for the cueing scenario.

Chapter 6

Manipulating experience: The Logisticians story

Pierre Dillenbourg, Patrick Jermann, Guillaume Zufferey

Up until this point in the book, we have mainly been discussing the connectivity gap between the different sites of the dual VET system and our technological approaches to bridging this gap. Starting with this chapter, the focus shifts to another gap we identified in the VET training, which we call the skills gap. As previously described in the introduction, the skills gap is one of the current problems of the dual VET system. Many apprentices do not perceive the more theoretical knowledge they are learning in school as useful or relevant for their work, based on what they see in the workplace, while many of the skills students need in the workplace are not discussed in school. Of course, our goal is not to eliminate this skills gap, as this would render either the school or the workplace redundant. Rather, our goal is to develop technologies to bridge that skills gap by helping students make connections between the things they are learning in school and the workplace. Ideally, they would understand why the things they are presented with at school make sense to their occupation, despite not being able to connect them with what they actually do in the workplace.

This shift from the connectivity gap to the skills gap allows us to turn back the clock. In actuality, the projects dedicated to closing the connectivity gap and those dedicated to closing the skills gap ran in parallel. So, we return to the very beginning of the Dual-T project to tell you the story of how we discovered the skills gap and how we began to develop and evaluate technologies to bridge it.

An awkward beginning

Have you ever heard about serendipity in research? At the time of submitting a proposal to obtain this leading house, our EPFL lab had obtained interesting results on location awareness technologies for team problem solving (Nova et al., 2005). We followed this direction when applying to obtain the funding for this leading house following a call from SERI. The idea was to provide apprentices with a geo-visualisation of the flows of goods and persons in a typical warehouse. We obtained the funding but quite rapidly drifted away from this original plan. Why? As we were not very familiar with this professional context, Patrick Jermann and Guillaume Zufferey initiated their work by conducting visits to multiple warehouses and asking apprentices and their bosses to describe their daily activities. Thanks to Michel Tatti, director of the professional school in Yverdon (Vaud), they also interviewed multiple teachers: two of them – Jacques Kurzo and André Ryser – remained involved with the project.

An interesting finding of the workplace visits has been that the apprentices working in small warehouses with one to two employees (e.g. building materials wholesaler) faced logistics questions more often than those working in fully automated warehouses, such as in some large companies. The former came to reflect on some optimisation principles while trying to store frequent sales products close to the truck delivery platform. The latter group was mostly scanning codes on goods entering and leaving the warehouse. Technology is known to have a potential de-skilling effect.
Optimising warehouse storage is a skill that logistics assistants have to acquire (it is an objective of the federal ordinance). However, they rarely practise it in their workplace: it is not often that a warehouse needs to be fully reorganised and, when it is, it is the warehouse manager who re-thinks the organisation, not the apprentice. In the visited warehouses, apprentices had to operate rapidly to be effective. They did not reorganise. So, it is left to the school to provide apprentices with those skills they might need later on in their careers, when they gain more responsibilities and not only with the skills they need during their apprenticeship. School teachers confirmed that logistics was, therefore, quite difficult to teach. Not only is logistics quite abstract, but since apprentices do not use these skills during their week, they barely

give meaning to the logistics principles presented by the teachers. Teachers asked us if we could do something about this situation around such a skills gap and if there was a technological solution.

Guillaume and Patrick had many discussions with logistics teachers for co-designing the activity and the technology. Many scholars have a naïve view of co-design as asking teachers what they need. However, co-design is not a one-way process. It is a ping-pong of ideas between researchers and teachers, an interactive and sometimes frustrating process of refining ideas. But sometimes something clicks. One day Patrick and Guillaume met the two Yverdon logistics teachers with two small-scale wooden shelves they had fabricated. This unlocked the co-design process. Having something concrete in hand enabled teachers to suggest concrete activities. As a result, we built what we called a TinkerTable (Figure 6-1), a first attempt to build a simulation of a warehouse with 'augmented' potentialities.

Figure 6-1 · TinkerTable, the ancestor of the TinkerLamp

The TinkerTable was an **AR** system consisting of a 2.5x1.5m table covered with whiteboard material and a 2.7m high armature carrying a camera, a projector and a mirror. The adjective 'augmented' refers to how digital information is overlaid on real objects or their images. A beamer projects visual information on the shelves (representing the contents of these shelves) and on the table (the movement of forklifts). The beamer is contained in the TinkerTable, and the mirrors increase the focal distance in order to cover the larger table surface. Included in the TinkerTable is a camera, which reads, via the top mirror, markers placed on the top of the shelves to position them in the 2D space. A technical constraint of AR is to accurately align the digital information with the real objects or real image. Today, most AR systems are see-through tablets (e.g. one looks at a painting and additional information appears on the tablet) as well as increasingly cheaper head-mounted displays.

In human-computer interaction (HCI), this type of interface is referred to as a '**tangible interface**'; in our case, users configure their warehouse by actually moving around physical shelves on the table (tracked by the camera) and not simple icons on the screen to be moved by a mouse, as is often the case in a traditional computer simulation. This is a funny historical loop since, after 'direct manipulation' interfaces appeared 40 years ago, icons replaced physical objects (desktop metaphor, trash icon, windows). We will see in this chapter how much physical manipulations matter as compared to the cognitive activity of organising a warehouse.

As you will notice, the technology was rather cumbersome. There was only one room in the school that was high enough to accommodate this device. One could also put one table in that room and the table could accommodate six to eight apprentices only. So, the teacher had to split the class into two subsets and coordinate with a colleague to handle the second half-class. We, therefore, kept the projector-camera idea but moved to a more transportable version.

The TinkerLamp evolution

We immediately decided to reduce the size of the system so that it could be placed on any desk. As VET classrooms often include around fifteen students, our intention was to place four smaller systems in the same classroom, with three or four apprentices around it. In line with previous projects done in our lab, we called this smaller system TinkerLamp. However, it is quite hard to have two or four students interacting around a computer. Quite often, one student takes the keyboard and mouse and controls most of the interaction, leaving at least one or two students out of the loop. With a tangible interface, however, it was pretty easy for at least three students seated around the TinkerLamp to be involved in the manipulations. In other words, tangible interfaces facilitate collaborative learning. That is not a point we want to develop in this book but Bertrand Schneider, who did his master thesis with TinkerLamp, continued this line of research when doing his PhD in Stanford (Schneider et al., 2018).

After an over-expensive prototype, we developed several versions, as illustrated in Figure 6-2, some (models 1,2,3) with one mirror, model 4 without any mirror and model 5 with two mirrors. Model 4 was the cheapest and easiest to calibrate (due to the absence of any mirrors) and has, hence, been used in many of the experiments described here. Model 5, the one that has been commercialised, was designed by Katarina and Vincent Nanchen. A video of the final model in action can be seen at *www.youtube.com/watch?v=CYuDYWYxKb8&t=2s*.

Figure 6-2 · Multiple designs of the TinkerLamp

The reader might consider that the shape of the device does not really matter as compared to the cognitive activities triggered by the warehouse simulation. This is not totally false, but some form factors do matter for daily classroom practices. For instance, the apprentices could more or less hide themselves behind model 3 (nicknamed the Pinguin), while teachers needed to keep them in their line of sight. Model 4 is elegant but cumbersome to store, as compared to model 5, which can be disassembled into a few parts. Model 2 can also be folded, which is useful when it comes to storing them in the classroom cabinets, but it is very heavy. At the end of the chapter, we will come back to these practical considerations of classroom life under the concept of classroom orchestration.

Does manipulation matter?

What is the cognitive difference between plastic shelves on a table as compared to moving icons on a large tablet computer placed on the table? These tiny plastic shelves are not very different from icons; they are quite visually different from real shelves and can simply be considered as 3D icons. Does the physical manipulation of objects matter? Nowadays, it would be easier to develop this as an iPad application (which only appeared in 2010, after we developed our TinkerLamp).
First, we conducted an experiment focused only on manipulation. We gave the participants 40 layouts to build either on the TinkerLamp or on a tabletop surface that we designed. The latter was basically like a big iPad running the same application as the TinkerLamp. All of the forty participants were significantly faster with the tangible interface than with the tabletop interface: on average, it took them about five minutes less to move shelves to the forty configurations than on the touch interface (Lucchi et al., 2010). Indeed, we are used to manipulating objects on a surface. Apprentices could easily grasp four shelves or more and move them, or even move an entire row of shelves using the front arm. In other words, tangible objects increased the usability of the task. It is not because of moving shelves that one learns anything. One might move chess pieces randomly on the chessboard without ever learning chess rules or strategies.

Two elements were required to turn this interface into a learning environment: a set of activities to be achieved and a feedback mechanism. First, teams of apprentices received an exercise description, with their goal printed on a paper sheet (Figure 6-3, left) that had the same visual markers to be positioned by the system. The left part, placed out of the camera's field of view, included the instructions for the apprentices' exercises. The right part had the input/output section. The apprentices could, for instance, select which type of forklift would be used in the bottom pane ('chariots élévateurs') as different forklifts require more or less space for rotating. Option selection was performed by moving a black token on it: this is the equivalent of a mouse click. The paper sheet was also used to display feedback, such as the percentage of surfaces used (Figure 6-3, right).

Second, once they considered that their warehouse layout was satisfactory, apprentices could run the simulation. Tinkerlamp would beam the movement of forklifts to carry boxes from the truck to the shelves and vice versa. This might take hours in a real warehouse. In our simulation, the process is dramatically accelerated. The simulation estimated the warehouse performance in real-time, that is, the average time to move a box from the truck to the shelf (see box 'Temps moyen par palette'). Apprentices enjoyed comparing their performance with their neighbours'.

Why do we give the reader so many details of the interface? Every computer-based simulation needs two spaces: the simulated space itself, where the phenomenon is manipulated and simulated (for instance, a chamber with particles in physics) and a control space providing functionalities such as running, pausing, recording an experiment, deleting or comparing results. In standard simulations, these two spaces are two panes or windows on the same display. In our case, as the tabletop is the simulated space, we invented a paper-based interface for the control functions. In some way, using a tangible interface forced us to complement it with a paper interface. Ulrich Hoppe, a member of our advisory board, questioned this media continuity, for instance, querying whether apprentices would handwrite the simulation results on the sheet. It is true that, today, these sheets could be replaced by a tablet computer. However, we discovered several advantages to paper: 1) apprentices write their best results as beamed on the paper and bring their sheet to the blackboard when asked by the teacher; 2) the co-design of these sheets with teachers is pretty easy: Patrick and Guillaume simply sketched the solution on paper; 3) teachers then had a folder with many exercises covering part of the curriculum. There was no need for a login and a password, and no need to find the right URL: they would simply select the sheet of the day in their folder; 4) teachers could easily take notes on their master sheets, for instance, with interesting parameter values, and make copies for colleagues. Paper is ubiquitous in education and well adapted to the classroom routine for storing, distributing, collecting and grading paper sheets. Paper is not only a legacy from pre-digital times: sheets have interesting usability properties for classroom routines. This paved the way for other projects involving other paper properties: rotating, folding and overlapping (see Bonnard et al., 2012a, 2012b)

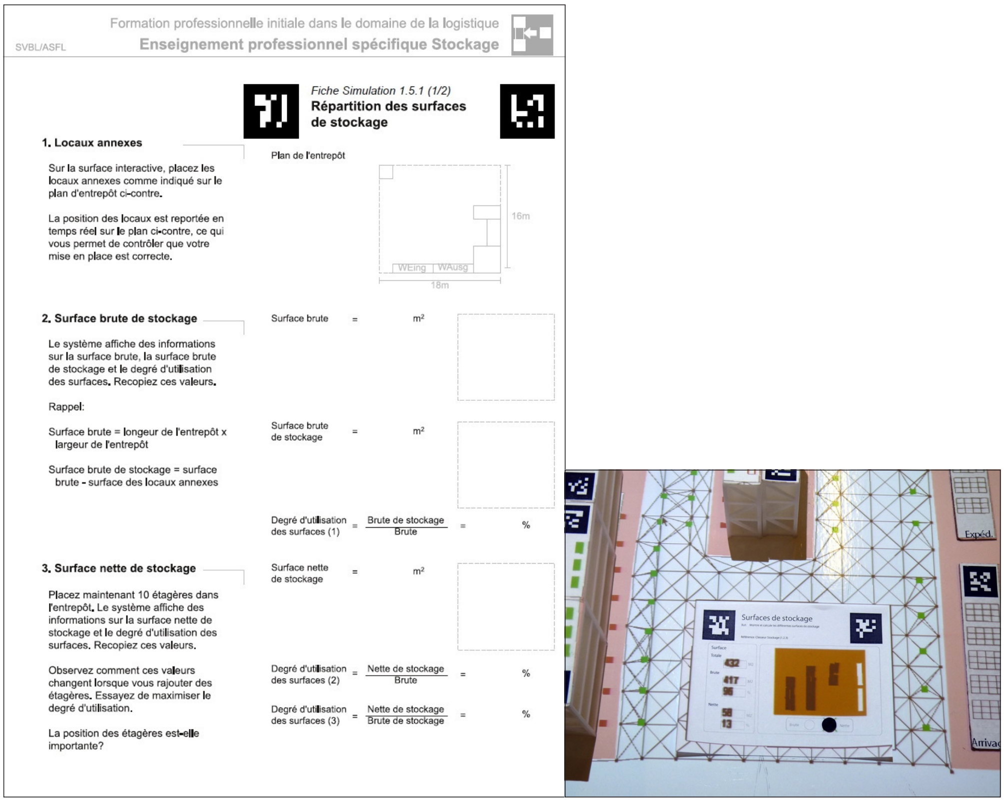


Figure 6-3 • Paper sheets as inputs and outputs (to be fixed)

As the learning environment has been enriched with activities and simulations, we faced the key question: does this tangible manipulation generate better learning gains than similar activities previously carried out in these classrooms? We conducted a new experiment with 82 apprentices from the same school, with some using the tangible interface and others using the previously described touch interface (Schneider et al., 2010). The participants were familiar with the Tinker environment since they had used it at least once before the experiment. We gave them the following goal: '*You have to build a warehouse with the maximum number of shelves possible. This is your primary goal. Moreover, the efficiency will also be assessed (i.e. the mean distance from each shelf to the reception and expedition docks). You will have approximately 25 minutes to build your warehouse in order to maximise the space used. Try to make most of the shelves accessible and to maximise the space used.*' The apprentices worked in groups of two. We looked at the overall performance of their warehouse as well as their ability to answer logistics questions in a pre-test and a post-test. Two criteria were used to evaluate the performance of each dyad: the number of accessible shelves in the warehouse, computed automatically by the software, and the average distance from the expedition and the reception docks to each shelf, obtained by analysing the logs.

What did we find? The apprentices in the tangible condition performed better (i.e. they built warehouse layouts containing significantly more shelves (Figure 6-4, left)), and the warehouses they built were marginally more efficient. One advantage of 3D shelves is that they facilitate the estimation of the distance between shelves based on the height of shelves; they give some intuitive scale that avoids non-accessible shelves being built.

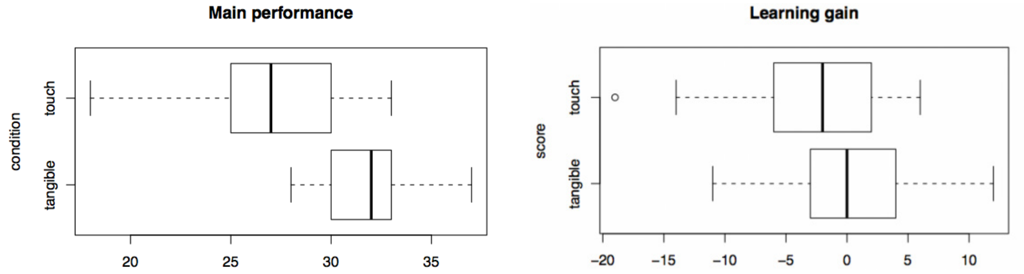


Figure 6-4 • Comparing apprentices operating with the tangible interface or a multi-touch interface. Note that the learning gain could be negative as the post-test was more difficult than the pre-test.

We found a smaller difference in learning gains, which were computed subtracting the pre-test performance from the post-test. The average gain was 0.43 for the tangible condition and -2.5 for the touch condition . A multilevel analysis yielded a significant effect , which confirms the hypothesis that the tangible interface would have a positive impact on learning gain (Figure 6-4, right). We analysed if some other variables might explain the advantage of tangible manipulation. We asked all participants to rate how playful the simulation was. There was surprisingly no significant difference between the touch and tangible conditions. Additionally, we checked whether the quality of collaboration was higher in the tangible condition using the rating scheme developed by Meier et al. (2007), but again the difference was not significant. The main difference between the two conditions turned out to be how often they moved the shelves, that is, how intensively they explored the space of possible designs. On average, they moved the shelves 176 times (SD = 73) in the tangible condition versus 130 times (SD = 28) in the touch condition.

At this point of the research, the pedagogical value of tangibility seemed to have little to do with the cognitive effects of physical manipulation. The relationship between cognitive operations and physical manipulations has inspired schools of thought since Froebel and Montessori, and this hypothesis is mentioned by scholars promoting tangible interfaces (Zuckerman et al., 2005). However, our work neither confirms it nor rejects it. While the link between physical manipulations and cognitive operations may exist when children juxtapose Cuisenaire rods, this embodiment of cognitive actions was not demonstrated with our logistics teenagers.

Does classroom orchestration matter?

The previous study was well controlled, with two apprentices coming to use the TinkerLamp in a laboratory under the control of researchers. It was then time to move to classroom reality, thanks to the collaboration with teachers. The study involved four classes over two days (two times two classes during a full day), with a total of 60 apprentices in their second year of apprenticeship (Zufferey, 2010). Each class was familiar with the Tinker environment because it had been used several times during the year. We used a within-subject experimental design, one class using the TinkerLamp in the morning and paper in the afternoon, the second class doing the opposite, so that the same teacher could do the activities with the TinkerLamp with both classes. We gave them different realistic tasks to do in each session. The results were disappointing: not only did we find no significant difference between the tangible interface and paper-based activities, either on declarative knowledge or on transfer questions, but the learning gains were very low in general. That is the life of an EdTech lab operative: we design cool technologies; we test them in real classrooms and then we cry! We understood that when we gave such precise instructions to the teams, the teacher felt out of the loop, mostly observing their apprentices (many of whom did not complete all the tasks).

So, we redesigned the activities to give a greater role to the teacher. We improved our TinkerSheets to support the debriefing activity: this is the moment when the teacher (Figure 6-5) asks each team (there are four lamps in the classroom) to copy onto the whiteboard the warehouse plan beamed on their TinkerSheet. The teacher asked them to compare the various values of their solutions: one solution might maximise storage surface but as forklifts have no space to cross each other in the alley, they will slow down and the average performance will be lower). As Schwartz and Bransford (1998) noted, 'there is a time for telling': a phase of exploration with a simulation such as TinkerLamp becomes effective if it is followed by a moment when the teacher introduces the key concepts based on the apprentices' experience. In this study, the teacher had a greater grasp of classroom activities and everything went much smoother.

Figure 6-5 · The four student teams have copied their warehouse map on the whiteboard and the teacher will compare surface usage and warehouse performance (time to bring a pallet from the truck to the shelf and vice versa): for instance, narrow alleys increase storage surface but forklifts may have difficulty crossing them.

This was about the time when Guillaume Zufferey completed his PhD, soon followed by Son Do Lehn. He ran a new experiment with 61 apprentices: those using TinkerLamp performed better than those using paper, exploring twice the warehouse designs and managing to fit significantly more shelves in their warehouses (Do Lehn et al., 2010). However, the post-test revealed no significant difference in terms of understanding the concept or in terms of problem solving. Again, we design, we test, we cry. Son then conducted further studies and realised that the best teams did not move the shelves too often. They reflected a bit more about what to modify in the warehouse and then implemented these measures. The worst teams did the opposite, moving shelves frequently and running the simulation too quickly, without much reflection. Son described this pitfall of tangible interfaces as a '**manipulation temptation**' (Do-Lenh et al., 2012), a concept that could have come from the Vatican: our tangible interface afforded this kind of reflection-free unstructured exploration.

Son designed a simple solution to reduce this problem. He gave teachers a paper card, called an orchestration card, that the teacher could show to the camera of the TinkerLamp (the card had a fiducial marker) to block or unblock the simulation (Figure 6-7 left). At the outset, the teacher would block any simulation and wait for the students to call him when they wanted to run the simulation. The teacher would then ask them to formulate a hypothesis about whether their newly designed warehouse would perform better than the previous one or not. If the team simply replied 'yes', the teacher would ask them to explain why it would be so. Asking learners to make **predictions** is a fundamental education trick to trigger reflections, as opposed to the random tinkering referred to by Son as 'manipulation temptation'. Edith Ackerman has a nice way of referring to the complementarity of tinkering and reflections: learning alternates **'heads in' and 'heads out'**.

We observed how difficult it was for the teacher to get the attention of learners in his class. We realised that a cool technology such as the TinkerLamp had become a distraction for apprentices. Teachers willing to give a two-minute message needed several minutes to disengage apprentices from the simulation and get their attention. Another orchestration card tackled this issue: a 'pause class' card (Figure 6.6, right), shown to any of the four TinkerLamps in the classroom, would simply freeze all simulations. Teams would not lose any data; the lamp would simply display nothing during the teacher's explanation. Then the teacher would display to the lamp the other side of the orchestration card and each team would pursue its work. Figure 6-6 (right) shows the teacher walking between team tables with a few cards in his hands, ready to use them. In later studies, we realised these cards are very simple to use by teachers as long there are only a few of them (we realised this later after making the mistake of designing too many cards: the teacher wasted time finding the appropriate card).

Figure 6-6 • Orchestration cards to block/allow the simulation (left), which could block all lamps in the class (right). A teacher walking around the class with the cards behind his back.

Our point here is not really to talk about orchestration cards; this is a concept specific to our environment. Our message is more fundamental. We learned that when one designs a piece of technology that is more interesting for learners than what the teacher could do or say, this introduces some kind of competitor to the teacher, something that would make their teaching more difficult. No reasonable teacher would be pleased to use a technology that spoils their teaching. We often hear that teachers are not familiar enough with digital technologies. This is hard to believe in Swiss society because it implies that they can neither book a concert nor an aircraft ticket, do their tax declaration or save their holiday pictures. Rather, Swiss teachers are technologically mature enough to discriminate between technologies that facilitate their work and those that make it more difficult. In some way, the TinkerLamp disempowered the teachers in keeping control of their class and the orchestration cards were one of the solutions necessary to re-empower them. Other environments may need other forms of empowerment for teachers.

The notion of empowerment and control expressed in the previous paragraph may shock some readers. They are often associated with discipline in lectures. We do, however, believe that, even in the constructivist approaches such as the ones we implemented, teachers need to feel what is going on and maintain leadership. There is one especially tricky moment, which is the debriefing phase. In the previously cited 'time for telling' approach or Manu Kapur's productive failure (2008) approach, the problem solving or exploration phase is followed by a moment where teachers reformulate the students' ideas that emerged, using the proper terms, clarifying definitions or explaining formulas. This second phase cannot be a simple PowerPoint prepared before the lesson, independently from what learners have done during the first phase. This formalisation phase has to build upon the ideas, errors, attempts, results or achievements of individuals and teams during the exploration phase. This is called the debriefing phase. The craft of **debriefing** requires a certain taste for improvisation (which not all teachers have) and self-confidence in their domain expertise and it also induces a high cognitive load.

We therefore designed and experimented on tools that facilitate the monitoring of the exploration phase as well as the debriefing phase. These tools are gathered into a so-called teacher's dashboard that collects information from the four TinkerLamps and proposes several visualisations. Figure 6-7 presents multiple visualisations expected to facilitate classroom management and debriefing. In the main top left panel, the teacher sees the history of the warehouses designed by the teams, with one team shown per row. The zoom shows a colour code that reveals the number of shelf manipulations: red means frequent moves (tinkering), green means some pauses (potentially reflective). There are control buttons equivalent to the orchestration cards. To facilitate debriefing, the teacher may select any two warehouses in the bottom part and compare their performances. **Debriefing is the art of building on what learners have produced**.

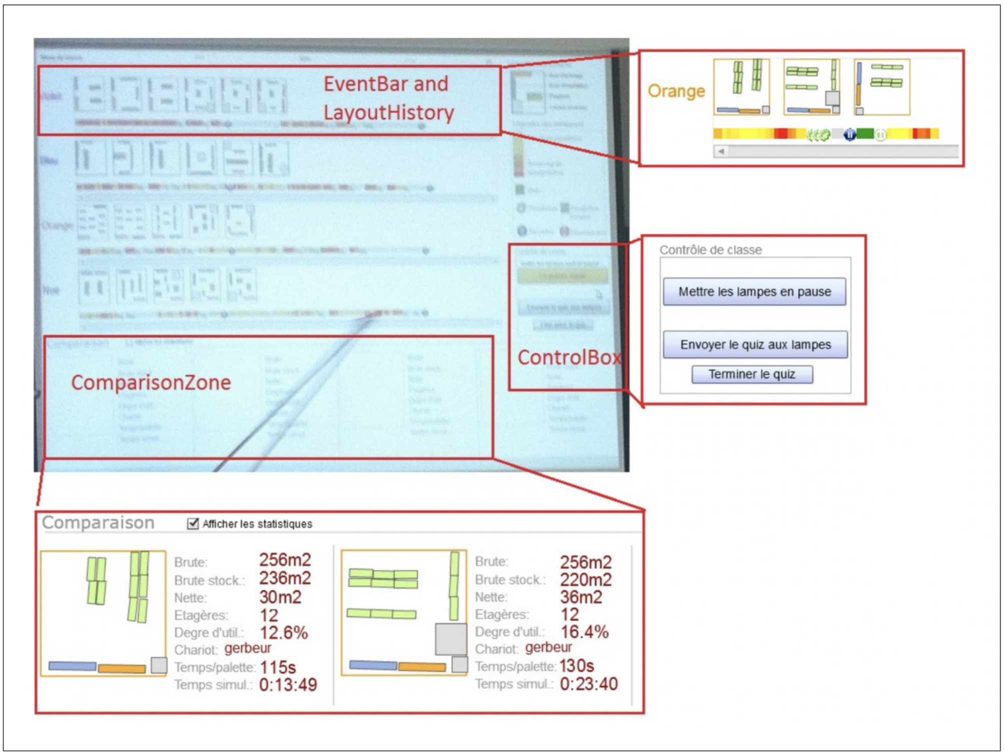


Figure 6-7 · Teacher's dashboard for orchestrating classrooms using TinkerLamp.

Pierre Dillenbourg was sceptical about the usability of these dashboards. Dashboards are supposed to facilitate teachers' work but many of the dashboards found in the literature on learning analytics increase teachers' cognitive load, as if a teacher can afford to devote a lot of attention to his computer display while the class is running. This pitfall did not arise. The dashboard was permanently displayed by the classroom beamer, with the teacher, walking around the classroom, often monitoring the dashboard and referring to it (Figure 6-8). Pierre was wrong: teachers used it easily and it worked quite well.

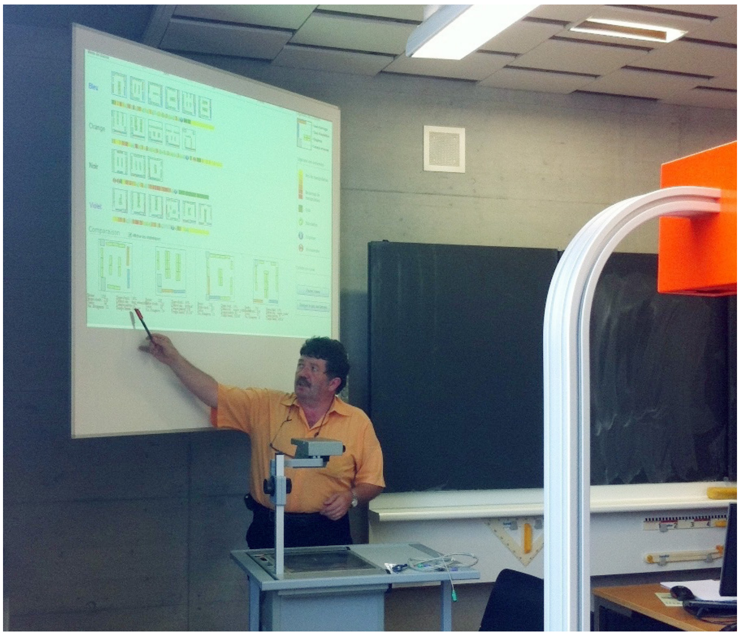


Figure 6-8 · Jacques Kurzo using the TinkerBoard to compare and contrast selected students' designs

How do we know it worked quite well? When using this tool, we obtained for the first time a significant increase in learning gains for TinkerLamp as compared to a paper-based lesson and obtained a significant difference both in terms of understanding and problem solving (table 6-1). These significant learning outcomes concluded a long process of designing, testing and improving our environment.

So what?

In the introduction, we broke down the chain linking a technology design to a learning outcome: the design of a technological solution (1) that enables rich VET activities and (2) that are, in turn, hypothesised to trigger cognitive processes (3). This chapter illustrates that chain. First, we demonstrated the usability of our manipulatives (1), that is, the short time it takes for apprentices to design a warehouse by assembling plastic shelves. Next, we co-designed learning activities with teachers. We had to add an extra technology feature, TinkerSheets, and integrate activities into the technological environment. It took us several cycles of co-design with teachers to obtain the rich learning activities mentioned in (2). Finally, we realised these activities did not spontaneously trigger the expected cognitive processes, which led to modest learning gains. We had to redesign the whole chain before obtaining a significant learning gain, again adding new technology features for teachers, a dashboard and orchestration cards.

Our progress along this causal chain reflects our growing awareness that **learning outcomes will depend on teachers as much as on digital tools**. In the introduction, we mentioned a fourth factor, the way the teacher orchestrates these activities in the classroom. We did not define classroom orchestration at the beginning of this book, but the reader will grasp this concept through multiple examples spread over this book. Some scholars simply call this classroom management. This concept is quite close to the need to keep some control in class. It is about the real-time management of individual, collaborative and class-wide activities and multiple classroom constraints. A principal lesson of this series of experiments is the importance of orchestration.

This is also the case for our 'pause the class' card, but there is much more than the notion of class control in the notion of classroom orchestration. This chapter presented multiple examples: the lock/unlock cards to avoid pure tinkering, the dashboard that summarises the activity of all teams so that the teacher keeps the global picture and, especially, the support for debriefing. Our colleague, Miguel Nussbaum, once described classroom orchestration as the logistics of classroom management, which is quite correct (and also funny in our context). Orchestration does not refer to a learning theory, but rather the daily optimisation of classroom processes. We designed other orchestration widgets in university courses:

- Automatic team formation: for instance, in forming teams of two students who obtained contradictory results in the previous activity (Dillenbourg & Jermann, 2010).
- Completion time prediction: if 80% of students have completed an activity, should the teacher wait for the remaining 20%, knowing the 80% will lose concentration? The system predicts how many more students will complete the task per additional waiting minute (Faucon et., 2020.)
- Prioritising the teaching assistant intervention: during exercise sessions, teams use a device, called Athe Lantern, that shows which exercises each team is working on, for how long and how long they have been waiting for help, and the teaching assistants can allocate their attention accordingly (Alavi et al., 2009).

Classroom orchestration concerns go beyond TinkerLamp and beyond VET. When considering any learning technology, one can distinguish between three circles of usability (Dillenbourg et al., 2011). The first circle is what is usually understood by usability in HCI, namely how efficiently an individual user interacts with the digital tools. This was the case in the first empirical study reported in this chapter. The second circle describes whether the technology facilitates teamwork or not. For instance, four apprentices may interact with the TinkerLamp warehouse more easily than around a tablet computer. **The third circle describes usability at the classroom level**, as illustrated in Figure 6-9. The reader may notice that the four TinkerLamps each have a different colour. Would the colour of a computer matter anyway? It does not if you consider the way an individual interacts with it (Circle 1) or the way a team works with such a lamp (circle 2). Put simply, it was a way for the teacher to address the team around the blue or red lamps. The colour facilitated the management of the classroom, represented by circle 3.

Figure 6-9 · Does the colour of computers matter?

We like the end of this story: inventing an innovative interface technology, focused on learner manipulation, brought forward the need to integrate features so that teacher interventions transform physical manipulations into cognitive operations that produce learning gains. Classroom orchestration is not a politically correct message in order for more attention to be paid to the role of teachers in technology design; it is simply a condition to make these technologies more effective for learning.

Appendix

	Paper/pen	TinkerLamp 1.0	TinkerLamp 2.0 NoTinkerBoard	TinkerLamp 2.0 WithTinkerBoard
Understanding	7.84 (2.85)	7.43 (2.82)	9.38 (2.03)	10.31 (1.70)
Problem-solving	5.16 (1.70)	5.15 (1.78)	6.44 (1.65)	6.59 (1.53)

Table 6-1 • The results of multiple experiments. TinkerLamp 2.0. includes orchestration cards and a few other elements. TinkerBoard refers to the teacher's dashboard.

Chapter 7

Augmenting experience: The carpenters' story

Pierre Dillenbourg, Sébastien Cuendet, Lorenzo Lucignano and Jessica Dehler-Zufferey

After our success using the TinkerLamp system with logisticians, we wondered if the same approach (augmented reality/tangible user interfaces) might be useful for other domains in VET. Luckily for us, around this time we were approached by the federal office in charge of VET, asking us if the TinkerLamp approach could be expanded to other professions. One idea was to transform our warehouse simulation into a supermarket simulation that could be used by salespersons, with shopping carts replacing forklifts. Another idea was to work on a simulation for police and security officers: in case of the emergency evacuation of a building or street, how would one place obstacles that would slow down the running crowds to avoid a stampede when the flow comes to a bottleneck. Ultimately, we decided to work in another field, which includes difficult learning objectives and concerns many apprentices, namely, training carpenters. We have to say that it has been a pleasure to collaborate with them, in particular Philippe Ogay from the Centre d'Enseignement Professionnel de Morges (CEPM), Sandro Melchior from Ecole de la Construction at Tolochenaz and all the members of the education committee of the Association Vaudoise des Charpentiers. Just as we did with the logisticians, we went to visit several companies, in their workshops as well as on worksites. We interviewed the bosses and the apprentices as well as the teachers in the school and those in the branch courses centre, whose director has been a great support.

After our initial discussions, we put aside the idea of reusing the TinkerLamp and focused on identifying skills gaps. The first one – spatial reasoning skills – rapidly emerged, while the second one – intuitive statics – was brought to us later by carpentry teachers. Let us focus on the first one. The work reported here was mostly carried out by Sébastien Cuendet and Jessica Dehler-Zufferey. Carpenters work on a 3D roof structure, usually defined by a 2D plan. They go back and forth between a 2D representation and the 3D objects. Spatial reasoning has been extensively studied in cognitive science and its malleability has been the focus of many academic works (Martin-Gutierrez et al., 2011). There are well-established tests that can measure spatial abilities, such as the paper folding test and the rotation test illustrated in Figure 7-1. They illustrate well what spatial reasoning means:

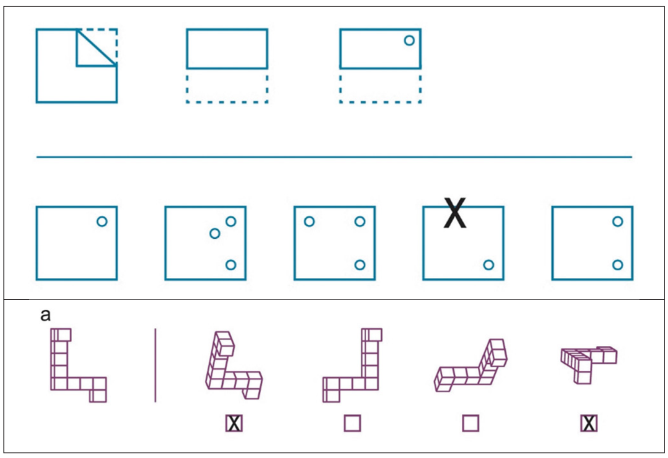


Figure 7-1 · Items from two tests measuring spatial ability: Paper folding test (top) and mental rotation test (bottom): In the paper folding test, the folding of a paper is shown in the upper part of the picture above the line and one hole is punched in it: how will the paper look like after being unfolded? Five possible options are shown in the pictures below the line. In the mental rotation test, which of the objects A, B, or C is a rotation of object 1?

The skills expected from carpenters are however more complex than what these tests entail. Roof plans propose two or three views of the same house: from the front, from the side and from the top (see Figure 7-2). Apprentices spend about three hours per week over three years to learn to draw these three connected views with millimetre accuracy. Some beams may not be parallel to any of the three orthogonal planes; hence their true length can only be computed by using graphical methods ('rabattement'). The problem is that apprentices seldom use or practise these methods in the workplace. In the companies we visited, roof plans are not drawn by apprentices but by a senior member who designs the roof and then another experienced member who cuts the beams; the role of apprentices is limited to assembly and fine adjustments. Moreover, experts do not draw on paper but use 'computer-aided design' (CAD) tools for carpenters such as CADWORKS®. Some of these tools not only produce plans as an output but also all parameters for a device that does the machining and drilling of wooden beams.

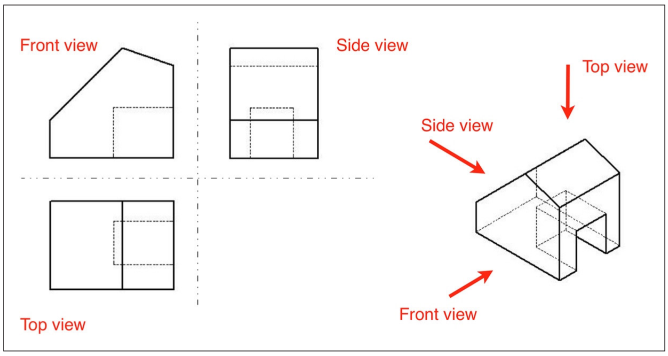


Figure 7-2 · The 3 orthogonal projections of the same structure.

In other words, we face here an opposite skills gap than in logistics. With logisticians, the school was trying to go beyond the needs of daily workplace practices. With carpenters, workplaces had embraced the digital transformation way earlier than schools, hence resulting in them being more technologically advanced. Nevertheless, drawing plans is so deeply encompassed in carpentry culture that it would be extremely hard to remove them from their curriculum. When we asked teachers about it, they argued that it was not possible to teach CAD usage as not all carpentry companies use the same CAD system. This is partly true, but some principles are common to all CAD systems. We face the same problem in any education system, including EPFL: it is almost impossible to build consensus on the removal of a course. We hear reflections such as 'an engineer who has never computed X by hand is not an engineer' or 'we had to go through it, so new apprentices should go through it' as if apprenticeship was like military service. As the evolution of professions requires new skills, e.g. additive manufacturing, either you lengthen the apprenticeship or you remove some contents. But in education generally, not only in VET, removing content is not done easily, as already portrayed in 1939 in the famous satire, The Sabre-Tooth Curriculum. When we asked carpentry managers whether drawing should be replaced by other skills to be taught at schools, they also declined the idea. It is true that, even if they use CAD tools, the carpenters we met are always ready to sketch for instance the detail of an assembly between two beams with the pencil they usually keep on the top of their ear. They accepted that drawing lessons could be shortened but stressed the fact that an apprentice needs to be able to read every detail of a plan and to go back and forth between the 2D plan and the 3D structures, as we said earlier. These meetings clearly defined our research challenge. Could we design learning activities that focused on these specific spatial reasoning skills, namely **connecting an object to its 3 orthogonal projections**, without spending so much time and effort in drawing them at school? Moreover, the target skill might not be practised in the workplace by the apprentices themselves, unlike what we have presented earlier for bakers, cooks, painters, clothing designers and beauticians (see Chapters 3, 4 or 5).

A new AR learning environment was designed for this purpose, tailored to the needs of this profession, an environment we called TapaCarp. It shares with the TinkerLamp application the goal to focus the apprentice's attention on the core of their skills, offloading the time-consuming tasks needed to get there.

In the AR workspace of TapaCarp, the orthogonal projections of a 3D object are displayed in real-time. In each orthographic view, the edges are depicted either as plain lines if they are visible from this viewpoint or as dotted lines if they are not. For the TapaCarp activities, apprentices did not work with models of full roofs but rather with small wooden blocks having different levels of 3D complexity. These blocks could be directly manipulated, that is, rotated on the table or placed next to each other. A difficult task for apprentices is to find the corresponding lines of the three orthographic views and the corresponding edges of the 3D object. This is a task that requires some degree of spatial visualisation skills. One trick to help connect them is co-variations or dynamic linking between objects and views: the human brain is well equipped to detect when two elements vary simultaneously. In Figure 7-3, TapaCarp shows the three projections of the complex wooden object that is placed in the bottom-right corner of the working space. When rotating the wooden object, some invisible edges become visible while other ones turn invisible. If apprentices had to do the same operation by drawing the same block before and after rotation, it would not take three seconds but three hours. The pedagogical augmentation is the dynamic linking between a moving object and its orthogonal projections.

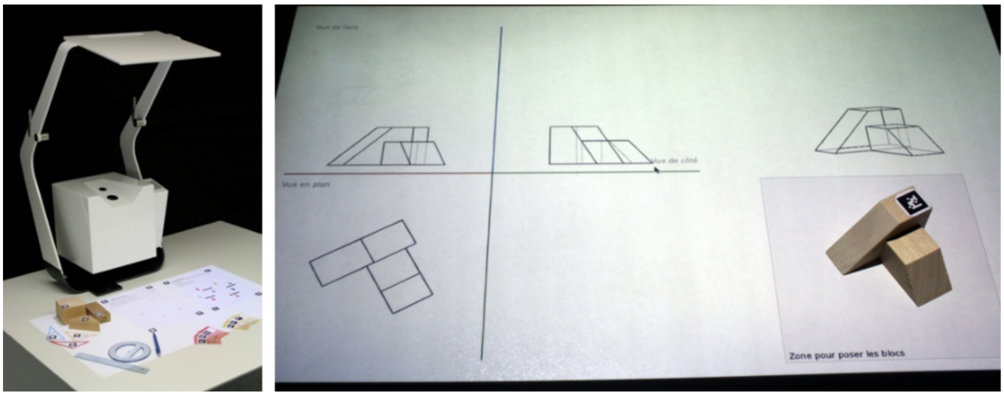


Figure 7-3 · The apprentice manipulates the wooden object and the TinkerLamp updates in real-time the three orthogonal projections.

In one of our studies, we questioned the usefulness of the wooden block since the digital representation of the wooden block could easily be rotated with a non-figurative input device as a mouse or a token, for instance. In order to test this hypothesis, we designed a study where 44 apprentices had to indicate on the 3 projections the line corresponding to an edge indicated by the teacher. The results show that the benefit of the figurative object was only significant when they had to identify an edge of the side view (Figure 7-4, right). This matches a general finding of our experiments: the mental visualisation of an object from the side is always the most demanding task for apprentices (and for us). Indeed, in this experiment, apprentices had a 15% error rate with the side view as compared to 6.8% and 5.8% for the plan and front views, respectively.

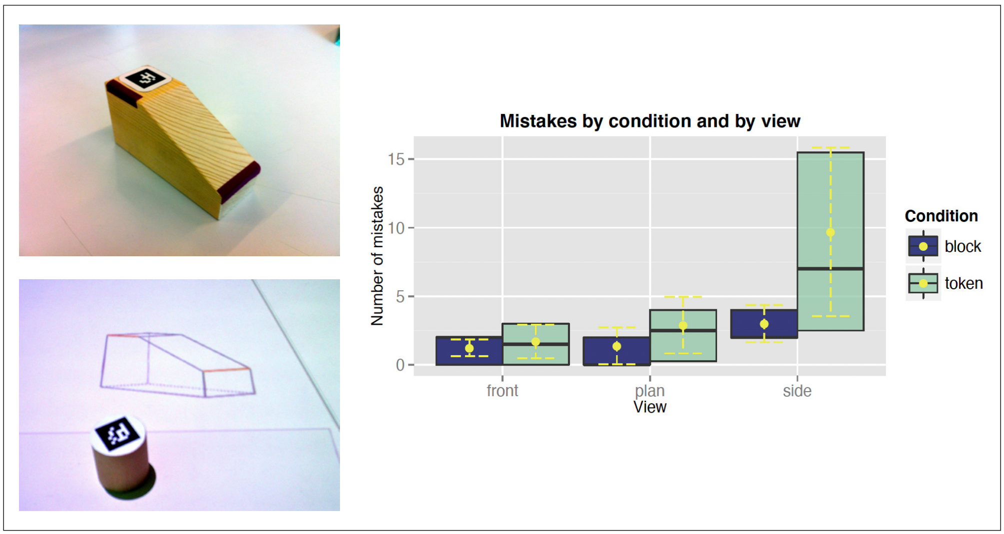
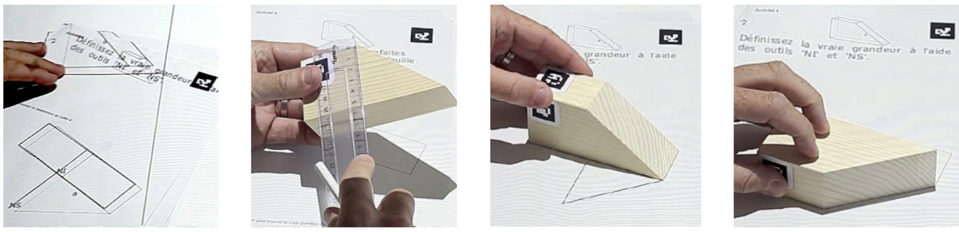


Figure 7-4 • Comparison of the number of errors (right) in different views while using a real 3D block (upper left) versus a simple token (bottom left).

To bring TapaCarp to schools, we designed a booklet with 11 activities covering a 50-minute session. Apprentices had to learn how to compute the true length of an edge that is perpendicular to none of the three views, using the technique called 'rabattement'. As compared to the exploratory pedagogy developed in logistics (see Chapter 6), this booklet was closer to a step-by-step lesson plan as in the mastery learning approach. Instead of displaying information on the table, TapaCarp beamed the orthogonal projections and other information pieces directly onto the booklet, recognising the fiducial markers in the top right corner (Figure 7-5). We designed an augmented booklet where the task instructions were printed in advance and the block projections were added in real-time. They also used multiple small cards, such as the orchestration cards in TinkerLamp, to do such operations as showing or hiding the construction lines that connect the orthogonal projections. Under the teachers' influence, the booklet also included drawing activities (hence the drawing tools in Figure 7-5), which is an advantage of beaming on paper. In the end, the annotated booklet could be graded by two judges independently of the TapaCarp environment.

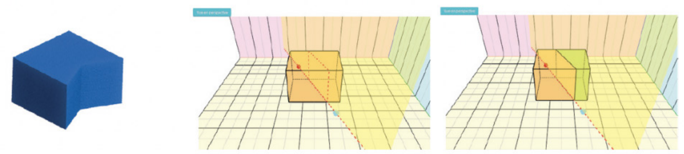
We compared 24 apprentices using TapaCarp in pairs and 19 using the previously mentioned booklet and wooden blocks, but without the augmentation. The booklet was supposed to be sufficient for self-instruction in the paper condition, but it turned out that the teacher in the paper condition, probably challenged by the experiment, intervened massively during the lesson while the one in charge of the AR condition did not. As a result, the learning gains were almost (marginally) significantly higher in the paper condition. In terms of usability, we realised that the TapaCarp interface included too many paper cards for various actions, leading to time wasted in finding the right card. As we wrote in the previous chapters, cards are very useful if users only manipulate a few of them. Apprentices found creative ways to combine the paper sheets, the beamed information, the wooden block and their tools, as illustrated in Figure 7-5.



(a) Paper with projection. (b) Tool with block. (c) Block with paper. (d) Block with paper.

Figure 7-5 • Integration of interface components – the leaflet sheets (one can see the fiducial marker), the beamed projections, the block and the tools.

Let us also report on an experiment that shows the limitation of a tangible AR system. In the previous experiment, the shape of the block did not evolve; it was manipulated as it appears. However, we wanted to touch on a complex skill that apprentices have to perform, which is cutting fragments of a beam, for instance, to make the joint with another beam. We implemented this activity in TapaCarp. The logic is more complex than what we have seen so far, as apprentices have to define cutting planes and then cut partially along these planes.



(a) Target Shape (b) Placing the cutting plane (c) Perform the first cut

(d) Perform the second cut (e) Select one fragment and remove it

Figure 7-6 • To end with the target object (a), the apprentice defines two cutting planes, one in green (c) and the other in red (d), in order to remove the blue part (d-e) (Lucignano et al., 2014).

While apprentices were virtually cutting the virtual object, the physical object in their hands did not evolve. Very quickly, the physical object and the virtual object did not correspond anymore. The object then became a simple manipulation token, as in the previously reported experiment. It is, hence, no surprise that when we compared students using the block as input versus a control group using a mouse, we obtained no significant difference in terms of duration or quality of the cuts (Lucignano et al., 2014). We considered using Styrofoam as a manipulative material and actually cutting it after each step, but it would have been cumbersome to run it with a class of 15 apprentices. The lesson learned is that using a tangible object as an input device in an AR system requires the physical object to remain visually close to the augmented object.

AR for intuitive understanding of statics

As we built a trust relationship with the carpenters' education committee at the cantonal level, the members came up with a new request. A new federal ordinance had just come out, which included teaching some intuitive understanding of statics, namely the equilibrium of forces in roof structures. The word 'intuitive' has no scientific measure so we use it here carefully. What is meant is that it is not about applying mathematically the laws of physics as for training civil engineers. Daily statics reasoning for an apprentice is, for instance, about the order of mounting or dismounting the elements of a structure. A 15-year-old apprentice may wonder which piece is most important to fix before leaving the work site when strong winds are expected for the evening. When carpenters have more difficult statics issues (e.g. constructing a chalet) they use specific software, and when they have statics challenges, such as a sports hall, they involve civil engineers.

Therefore, Lorenzo Lucignano developed a new environment, the StaticAR application. The background for the augmentation is the small-scale mock-ups of roof structures. The AR displays the axial forces along the beams and the amount of stress they are subjected to. This time we did not use a projector-camera system such as TinkerLamp but a see-through approach: the apprentice looks at the reality, a roof mock-up, through a tablet, which adds the statics information (Figure 7-7). Ideally, we would have liked that the apprentice simply wore a head-mounted display to look at real-scale roof structures but there were computer vision challenges: a roof structure is rarely visible in a global way, as it is very large and presents many occlusions and dark zones.

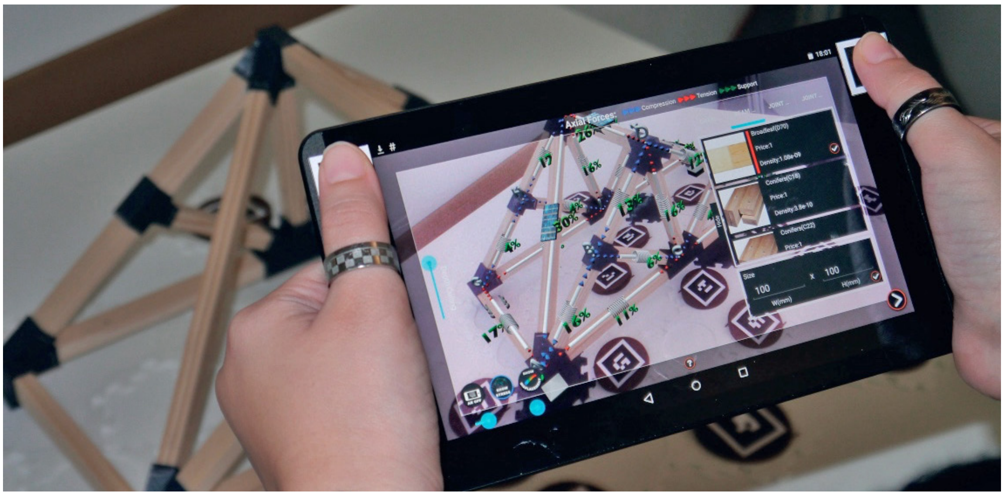


Figure 7-7 · AR with a see-through technique

The previously described notions of didactic and computational transpositions apply here, as we worked with simplified truss models. Trusses are the typical structural frameworks that sustain roofs. The analysis of a truss consists in understanding the nature of the axial forces acting on its members and how all pieces are in equilibrium so that they create a stable structure. There are several simplifications, such as the abstract nature of the connections (e.g. it does not matter if two pieces are connected with nails or with timber joints), not modelling the imperfection of the timber grain or considering the effect of forces that are not parallel to the parts of the truss. Despite such simplifications, the model is well suited for exploring whether the truss can sustain the forces or not, what size or timber to use for the parts or what happens when replacing one part.

The computational core of statics analysis is a customised version of Frame3DD, an open-source application released under the GPLv3 licence. The overlaid information depicts in blue or red whether a beam is under compression or tension. The type of timber is described with a few parameters that carpenters are familiar with (e.g. standard strength class). This description is used instead of the multiple parameters that characterise the complex timber models used in engineering classes.

We discussed with experts the best way to visualise forces, namely when beams are under compression or tension (Figure 7-8). We used springs and arrows as complementary representations of the same concept. The springs convey the effect of the force on the beams, while the arrows convey the reaction of beams on the joints. The notion of action and reaction might be taken for granted by people with a scientific background, but the fact that '*When the beam is compressed it pushes against the joints to keep the equilibrium*' is not a trivial issue and is not an intuitive physics concept. When looking at a particular joint, the arrows from the connected beams form a quasi-force diagram of the node (although non-axial forces are neglected), from which it is possible to observe how the equilibrium is reached.

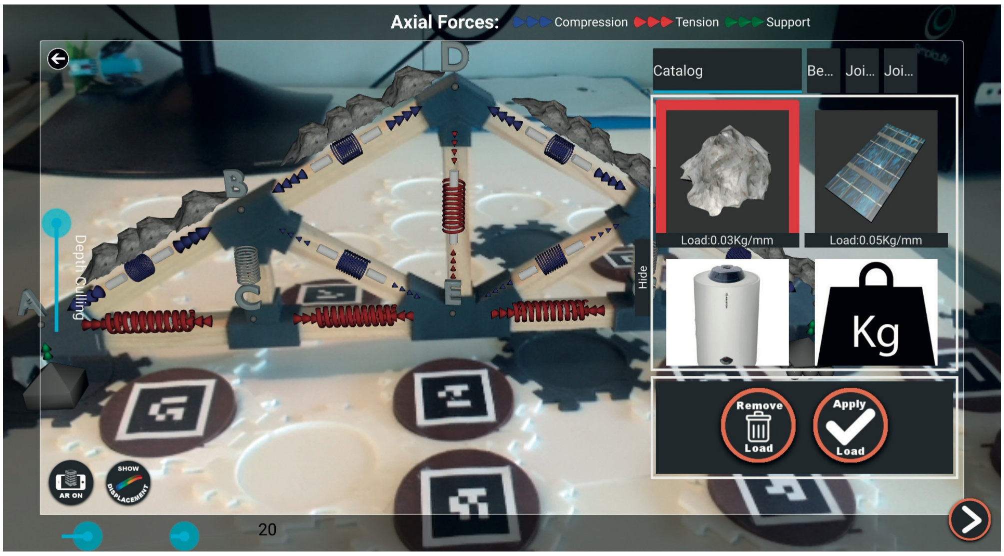


Figure 7-8 · Adding statics information on the beams

As in previous AR applications, we enabled the apprentice to explore the phenomenon by **manipulating** reality (Figure 7-8, right-hand pane). Apprentices could manipulate three sets of parameters (Figure 7-9). First, they could place loads on the roof, such as snow, solar panels, water tanks, or simply a large weight. Solar panels and snow are interesting issues for carpenters as they produce asymmetric loads: solar panels are placed on south-oriented roof panes (in the northern hemisphere), while snow melts slower on north-oriented panes, both cases creating a disequilibrium. Apprentices could also modify the beams themselves by choosing, for instance, a more resistant wood or larger beams, both having a non-negligible impact on costs. Finally, they could select a joint on the display and specify which type of support was present. If the load that apprentices place on the roof exceeds what the structure may support, the whole structure will collapse with a dramatic noise.

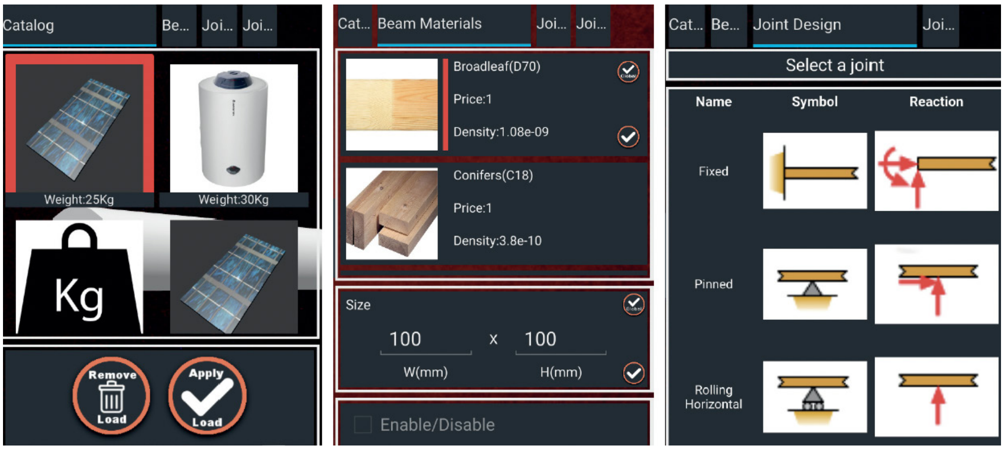


Figure 7-9 • Parameters that apprentices could manipulate

To further develop the intuitive grasp, the system could exaggerate 500 times the deformation of beams (Figure 7-10, left) or zoom in on a beam and further visualise the distortion (Figure 7-10, right)

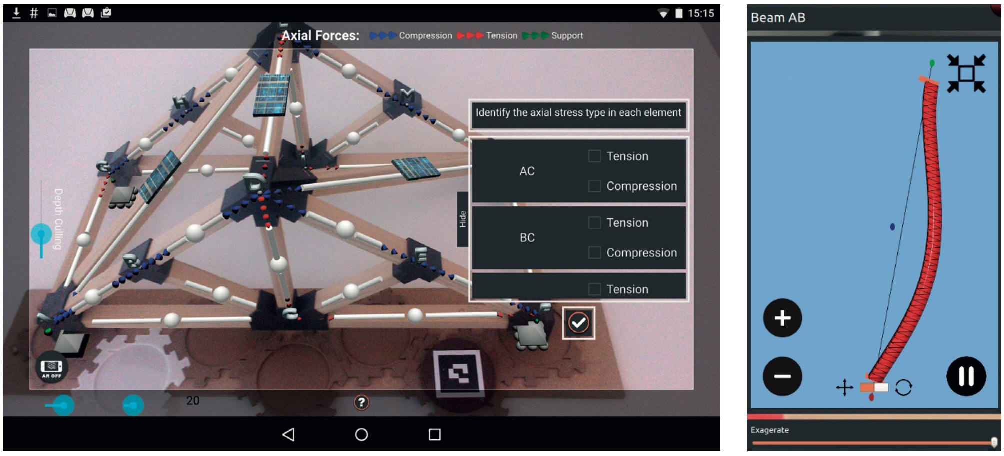


Figure 7-10 • Another way to visualise forces is to exaggerate the distortion of the beams as if the beams were not composed of wood.

As with the TinkerLamp, we did not expect apprentices to discover by themselves the laws of statics by playing with this great application, even for an extended period. There are limits to constructivism. Exploration through manipulation needs to be embedded in a pedagogical scenario. Here, like logistics, the pedagogical idea behind was 'a time for telling'. Apprentices would eventually encounter difficulties, and would not really know the laws of physics, but might pay attention to some elements and ask themselves questions that would be addressed during the debriefing phase. Another anecdote we can relate to is that when we ran the last study, the best result was achieved by the apprentice working in a company building ski ramps. Intuitive physics was probably playing a large role in his job. One of the worst results was from one working in a company making doors.
But we faced another question. Since apprentices did not physically manipulate the wooden mock-up or the weights placed on it, what was the added value of AR versus virtual reality? They could do everything on a tablet or a standard computer, changing parameters with their finger or mouse. What was the added value of moving the tablet around the mock-up as you move a lens over a mushroom? We hypothesised that the answer to this question would depend on two parameters – whether the structure was 2D or 3D and whether it was symmetrical or not. We, hence, experimented with the four models illustrated in Figure 7-11, top. We had 25 students who passed the test, with either the tablet placed on a tripod with wheels (hence, movable) or in their hands. We gave them three tasks to do per structure. Using eye trackers, we found that under both conditions, they rarely looked directly at the wooden

structure: only 1.2% of gaze fixations were directly at the structure, which questions the relevance of having it. However, we found that for the 3D structure, users actually moved the tablet around the 3D structures more than around the 2D ones, as illustrated by the heat maps in Figure 7-11, bottom. In addition, our analysis revealed that as soon as the person changed position, they were more likely to look at the structure. During the interviews, six participants explicitly reported that they quickly looked at the structure in order to decide the successive points of view. The main result is that looking directly at the physical object seems to sustain the spatial orientation of the user in the physical space when changing locations. It eases the alignment of the point of view given by the tablet camera with the natural point of view of the person. Hence, this translates into a more effortless navigation of the space during the AR experience.

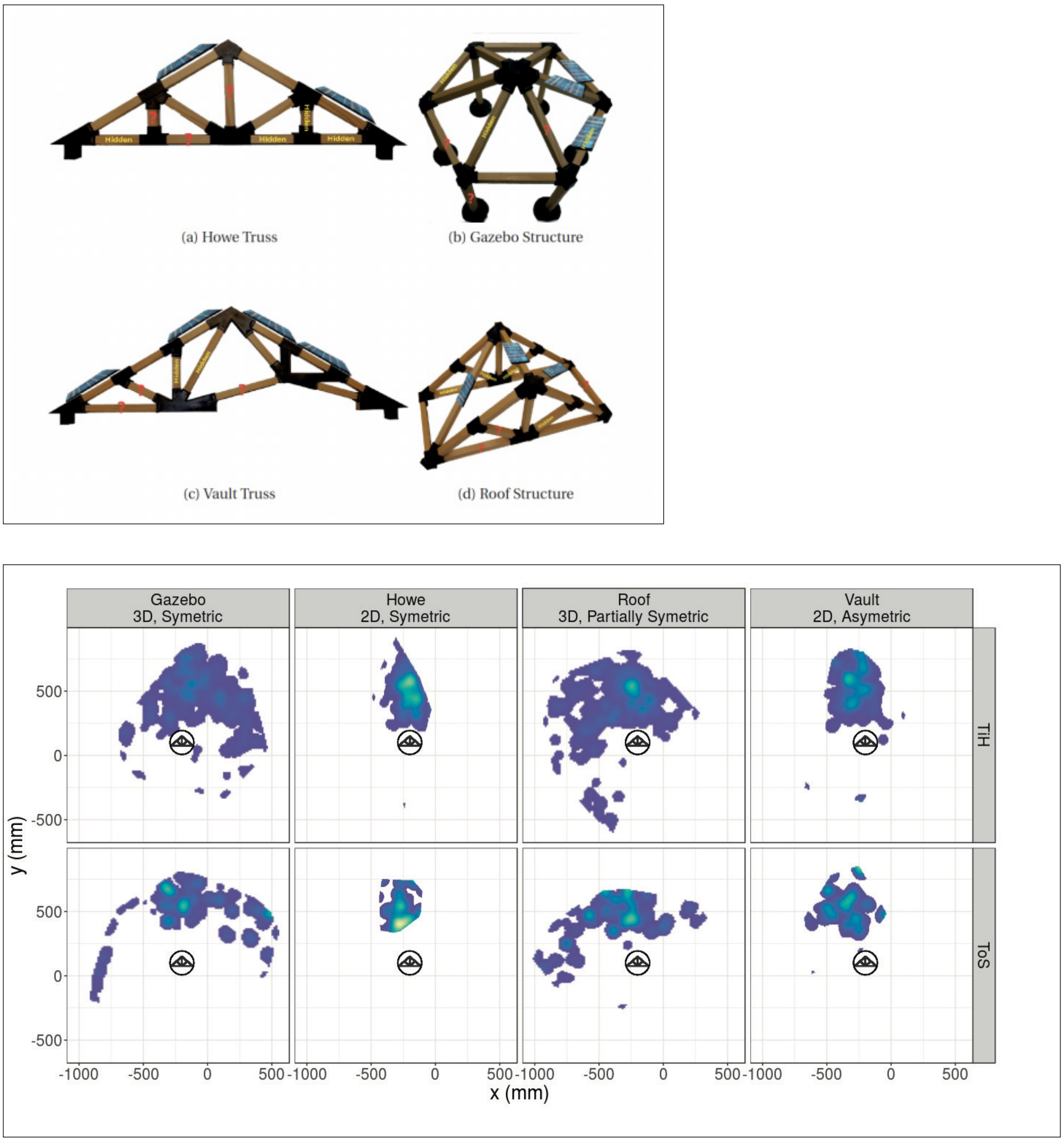


Figure 7-11 · On the top is the 4 roof models used in the experiment. On the bottom, the heat maps show the position of the tablets around the structure (in the middle) for the four models and in the two conditions, the tablets in the apprentices' hands for the upper row and the tablet on support for the lower row.

Reflections on our approach to augmenting reality

We developed several AR environments for VET. In the previous chapter, we presented TinkerLamp, which we developed and used for logisticians. This chapter introduced two more examples of AR for carpenters and the next chapter addresses yet other AR environments – for gardeners and florists. While many scholars strive to develop virtual reality (VR) worlds as similar as possible to reality, the AR examples that we developed for this project differ from reality. In the real world, we do not see forces in a roof structure unless it is going to collapse. The added value of StaticAR has indeed been to **make visible something that is normally invisible**.

The adjective 'augmented' is quite technical. It refers to the overlay of digital information on a real object or a real image taken by a camera. In the former case, when augmented real objects can be physically manipulated, as in TinkerLamp, some authors prefer to use the term 'mixed reality' (MR). This term evokes one powerful feature shared by different AR and MR technologies: the ability to blur the boundary between the physical and the digital realms. Unlike with VR, in which the entire visual scene is generated by the computer and the user is immersed in the virtual environment, AR and MR leave users their view of the physical world. A bi-directional link is created between the digital and physical entities, with the former reacting to the changes of the latter and the latter being enriched with computer-generated content.

The plastic shelves in TinkerLamp were both physical objects and input devices. In TinkerLamp, the physical-digital link resulted from advances in computer vision. Nowadays, any object can be an input/output if enriched with tiny sensors or actuators: the '*Internet of Things*' creates a continuum between the physical and the digital world. This is part of the blurring between the physical and digital worlds. While TinkerLamp used an ad hoc technology, most AR environments use head-mounted displays or see-through glasses (the user sees the normal view through glasses but digital information is added to the glasses). The core technological challenge in AR is to align the displayed digital information and the visual scene, combining computer vision techniques and 3D localisation. Despite this difficulty, AR technologies already populate the market and enterprise-ready systems have been successfully adopted in industrial workplaces.

Typical professional AR applications relate to the technical maintenance of complex machines in which technical information is added to different elements or the repair procedure is suggested in a step-by-step process. In the case of the task of changing a setting of a complex machine, for instance, it is useful to display information about the machine's elements directly on it, rather than in a handbook, for example, in order to make clear what the machinist is supposed to do and thereby avoid potentially costly and dangerous errors. Other applications bring transparency: a worker who has to drill a hole in a wall or a street sees the pipes that are invisible in order to avoid them or find them. These examples illustrate how the word 'augmentation' can be understood as more than the technical meaning of 'overlaying information'. It also means to 'augment' in the sense of enriching the task performed by users with new functionalities. The drill example brings a clear added value to a professional situation. We expect that more and more AR tools will be provided by the companies that sell equipment to other companies, as this may help prevent errors or accidents, which may, in turn, increase profitability. But what would be the equivalent useful functionality for education? If the system, for instance, informed the apprentices about the name of each piece in a car engine, it might help novices and avoid accidents but it would also prevent them from learning the names of these pieces. Any prosthesis may have a de-skilling effect, as a buoyance aid impedes the ability to learn to swim or a mobile phone call list implies one does not know the numbers of most of one's contacts. Such an argument about car diagnostic devices, the tablets that car mechanics plug into modern cars: do they prevent apprentices from developing appropriate diagnosis strategies or do they simply reflect the increasing complexity of car electronics? Clearly, our leading house is not interested in AR as a de-skilling technology but as a way to acquire specific skills, and the AR environment has to be designed in that way, as explained in this chapter.

Immersion: perceptive or cognitive?

One educational purpose of VR (more than AR) is to create learning situations where real situations are not accessible: it may be too dangerous for the apprentice herself (training firemen) or for another person (training nurses); it can be too expensive (repairing a Rolls Royce engine), too rare (a cable car accident), too fast (an explosion), so slow (plant growth) or too small (inside an engine or a vessel). A critical factor for these applications is the similarity with reality: would a fireman or a pilot emotionally react as if the situation was real? Nurses now often use physical, simulated patients: would they behave the same way if there was a real person in danger? Higher levels of immersion may go along with higher learning outcomes, for example, in terms of conceptual understanding (Georgiou & Kyza, 2018). Do not we entrust our life with people trained with highly realistic plane simulations?

The AR/VR provides apprentices with new experience but a means of **reflecting on what happened is required to turn experience into knowledge**. When training pilots, firemen or emergency teams, this reflection is introduced during proper debriefing sessions. Reflection is not understood here as a smoky quest for the meaning of life but as looking back to what happened during the AR/VR experience and making it accessible to analysis and elaboration. With our logisticians, reflection resulted from concrete activities, such as comparing warehouse performances, explaining where the differences in the performance of different warehouse setups came from or predicting performance indicators. With the carpenters, reflection resulted from turning the block slowly and predicting the different values the projection might display accordingly.

The quest for an immersive feeling is relevant for professions and is increasingly present in health VET, but it was not a goal of our work. The AR/VR environments we experimented on within VET were not designed to be immersive, apart from the Garden VR world (see the next chapter). Even for this VR, where gardeners walk in the virtual garden they have designed, we somehow sacrificed the visual realism so as to use free VR technologies (i.e. with a lower image resolution). However, immersion does not need to be fully perceptive; it can be cognitive. We do actually have anecdotal evidence of some sense of immersion with TinkerLamp. One apprentice explained that they set up the shelves in his warehouse so that they could smoke without being viewed by their bosses and reproduced this configuration on the TinkerLamp. He seemed to project his own experience of a real warehouse into this simplified mock-up with a few shelves. A complementary anecdote comes from a carpenter class in Luzern; they showed us a physical model of a roof made in steel, but acknowledged that they had stopped using it because the students found it hard to believe that a metal truss would behave similarly to a truss made of timbers. They found our wooden model enriched by digital information more acceptable.

Anecdotes do not make theories. But what is interesting is that the plastic shelves of TinkerLamp or the wooden blocks of TapaCarp have no visual fidelity with real objects, which have different shapes, dimensions and colours. **We sacrificed the perceptive fidelity for the cognitive benefits**. To be realistic, an apprentice would have to dismantle shelves in order to move them, but this has no role in the optimisation of warehouse layouts. Similarly, apprentices in the carpenter simulation could not change the size of a beam without a huge and costly effort.

In other words, the perceptive realism that leads to immersion may be critical for training where the emotional management of critical situations is a learning goal. This was not necessary for triggering the cognitive processes that lead to learning outcomes in warehouse optimisation or in the carpenter applications that follow. Instead of creating the feeling of immersion, we observed some form of **projection**, the apprentices projecting themselves inside the warehouse mock-up. Ultimately, this is not surprising. If you read a novel where the character is on the edge of a mountain and has lost his gloves and ice axe when realising a huge storm will reach the ridge within a few minutes, do you not project yourself onto that ridge? Simple words can make readers scared, anxious, happy or feel in love: projecting oneself into a situation occurs as our brain is talented to create or re-invent visual sceneries from verbal material, texts or ideas. And this creation is individual: two apprentices using TinkerLamp may highlight different visual scenes, mapping the abstract mock-up with the actual warehouse where they work, for instance, some being outside (construction material), some being mostly made of fridges. In the same way, some readers imagine the above-endangered mountaineer as an old man, others, as a young woman.

Didactic and computational transposition

When we showed the TinkerLamp to professional logisticians, that is, those in charge of the pharmacy storage for a large hospital, they expressed interest in using it as an optimisation tool for themselves instead of as a training tool for their apprentices. We had to discourage them: TinkerLamp is a simplified simulation, not a professional tool. We will see the same for our AR for exploring statics aimed at carpenters (StaticAR): professional carpenters who have, for instance, to design a sports hall, use very sophisticated, expensive and accredited software, not our didactic tools. Our AR tools bring a certain simplification of reality that might be useful to communicate to customers, but mostly they have a didactic function called 'didactic transposition'.

The French education community includes so-called 'didacticians'; these are scientists who are specialised in one discipline. Let us consider physics didacticians. Their expertise in the epistemology of sciences revealed the key differences between what is taught in school and the state of scientific knowledge. This difference is known as 'didactic transposition' (Bronckart & Plazaola Giger, 1998). To make a long story short, what is taught often is necessarily a subset of the scientific knowledge, often a simplification. The first time that projectile motion is taught, the physics teacher may introduce the angle, initial velocity and gravity but will probably neglect to mention air friction and the Coriolis force. Similarly, TinkerLamp offers numerous simplifications: all shelves are the same, all goods are the same (not fresh, frozen or fragile goods).

The didactic transposition is supposed to be an explicit decision made by the teacher or the designer. When the system includes a simulation, there is also a computational transposition (Balacheff, 1994). This refers to the fact that a computational model is always an approximation of the real phenomenon. The TinkerLamp has a simple model of a warehouse, in which forklifts drive at the same speed independently of the load they carry. They do not slow down when they turn, they take the same time to drop an object on the bottom layer and a top layer of a shelf, and so on. These details do not matter for understanding principles of logistics but it is important to point them out when educating apprentices. Depending on the profession and the subject of study, this awareness can be elicited in different ways. For instance, it can be done by comparing real phenomena and simulated models. In the approach proposed by Salzmann, Gillet and Huguenin (2000), students became aware of the computational approximation by relating the measurements taken from a real electrical drive with those coming from a MatLab® simulation. Apprentices will encounter an increasing number of computational models in their life so they must be conscious of the approximations provided by these tools and their implications.

In summary, the AR tools presented in this book result from both a didactic and a computational transposition. For instance, StaticAR does not implement the analysis of the stress state of the joints in a roof structure. The joints are modelled as unbreakable for two reasons: it seems a reasonable simplification for apprentices conceptually approaching statics; if they were not designed this way, StaticAR would have required complex modelling of the timber connections and fasteners.

So what?

The environments we developed for carpenters technically augment the learning activities with visual information related to the wooden objects used in the activities. Considering the pedagogical meaning of 'augmentation', the experiments revealed the added value (e.g. dynamic link towards orthogonal projections) as well as the limitations (e.g. the tangible block does not change over time in the cutting activity). The experiments also revealed that the devil lies in the detail, for instance, the see-through approach being more relevant for 3D structures than for 2D ones.

But our main point concerns the term 'reality' in AR. While many scholars strive to develop VR worlds as close as possible to reality, the AR examples so far differ from reality. In the real world, we do not see forces in a roof structure unless it is going to collapse. The added value of StaticAR has indeed been to **make visible something that is normally invisible**. In the real world, you do not see an object at the same time from two orthogonal viewpoints as in TapaCarp (unless using mirrors). Let us now consider TinkerLamp. In the real world, we do not move 4 shelves with two fingers and we do not reorganise a warehouse in 30 seconds. The added value there is to make **possible something that is normally impossible** in the real world.

In other words, the design of an AR must combine two properties. The first property is that the simulated situation should have greater cognitive plausibility than figurative realism: apprentices in TinkerLamp or StaticAR manipulate simplified representations that, nonetheless, allow the triggering of the target cognitive activity. The second property could be more surprising for the reader: **the pedagogical augmentation offered by these AR environments comes from their differences from reality**: to see the invisible or to experience something realistic (to some degree) but usually not accessible or impracticable. This does not only concern the perceptive differences (making the invisible visible) but also the interaction differences: **what can be manipulated easily in AR that cannot be easily done in reality**. Not all 'impossible' things are pedagogically interesting (e.g. putting two elephants on the roof). We believe the future of AR for education in general and VET, in particular, will be the ability of designers to invent differences between AR and reality and show that there is an added educational value for the learning task at hand.

Chapter 8

Expanding experience: The gardeners' story

Pierre Dillenbourg, Kevin Gonyop Kim

As our research questions evolved over the years, we also explored different vocational domains. This chapter reports on the work we conducted with gardeners and florists. It further explores the pedagogical value of AR, continuing from where we left off with the carpenters. In the conclusions of the previous chapter, we emphasised that a key pedagogical feature of an educational AR is the differences in the interactions it offers as compared to reality: what can be manipulated easily in AR that cannot be easily done in reality. In the AR tools presented in this chapter, the apprentice will indeed be able to do things that only magicians or gods can do: change the colour of flowers, move the sun or visit the future. What we report here is mostly the work of Kevin Gonyop, Catharin Oertel and Joseph Vavala.

Expanding experience

Workplace practices may include seasonal routines during which apprentices repetitively perform the same task. Young car mechanics in a Swiss garage will probably spend six weeks in the autumn doing almost nothing else than setting up winter tyres. Every car owner rushes to the garage at the first sign of approaching winter. Those many repetitions of the same task reinforce the learners' skills and contribute largely to making apprentices more efficient and reliable by installing dedicated routines, a benefit largely appreciated in many professions. No car owner would appreciate an apprentice being innovative in accomplishing such routine tasks. In other professions, however, imagining other solutions and coming up with extraordinary propositions may be more valued. Yet, while florist apprentices may spend days and days making nothing besides red rose bouquets when approaching St-Valentin day, nobody would really appreciate seeing all table decorations looking alike or every spouse's bouquet resembling exactly that of their siblings' and friends'. Many SMEs are specialised in some type of product, which defines their niche on the market or their style but narrows down the experience and the creativity an apprentice will collect during his or her apprenticeship.

This situation creates a kind of 'creativity gap' where apprentices have few opportunities to develop their divergent thinking skills within their domains. As we explained earlier, the school days partly compensate for this drawback, as apprentices share experience with other apprentices trained in different workplaces. The e-DAP platform (Chapter 3) and the Realto platform (see Chapters 4 and 5) explicitly encourage this sharing of experience among peers. The approach we followed in this project was to consider **AR as another way to expand workplace experience and develop creativity and imagination**. Expanding means starting from real experience, that is, a real bouquet or a garden project the apprentice has been working on. That is the R in AR. The A is to produce a diversity of objects derived from the real one, expanding virtually the set of objects the apprentices have encountered, virtually broadening experience and opening their minds to alternative solutions or propositions.

In other words, **we explore AR tools that generate innumerable virtual objects which could be produced as variations of the initial real object**. Imagine the design of the object is a sequence of ten choices with five options each: flower type one to five; colours one to five, length one to five. If you make the combinations for all options for all choices it makes a space of 510 options, that is, a space with close to ten million possible designs. First, this may lead the future designer to be lost in this high-dimensional universe. Second, this combination view is a very abstract, very academic way to consider design. It neglects the feasibility of some configurations, as well as the culture, the elegance, the functionality, the costs, the durability and the customer expectations. From an educational viewpoint, the question, however, remains: could an apprentice benefit from navigating through such a design space, that is, the space of possible variations obtained from a root object? The notion of design space may not be intuitive at all.

Exploring the design space

In the Erfahrraum model (see Chapter 2), apprentices capture their workplace experience through various means, including pictures and videos. We were interested in going one step further by capturing experiences as 3D objects. The image processing possibilities of mobile phones have, meanwhile, improved so much that one can simply do a tour of an object with a mobile phone camera and generate a 3D model of it. It is, of course, difficult to demonstrate 3D images in this book but the left bouquet in Figure 8-1 is a 3D object that can be rotated on any axis. The quality of the rendering is far from perfect, especially for complex internal structures, as we used free software. We were inspired by the possibility of applying a visual transformation of colours, as if we were using a different palette, generating bouquets such as the two presented in Figure 8-1 next to the original bouquet.

Figure 8-1 · The left-hand side bouquet is a 3D-model produced by doing a 360° tour of the real bouquet with a mobile phone camera. The next two bouquets are generated virtually by modifying the colours of the first one.

These early attempts initiated the core idea of this chapter: what if we enabled apprentices to virtually explore the space of variations of their object? We combined our general concept of Erfahrraum with the possibility of broadening the experience into the concept of 'Breiterfharraum' (one of us likes to invent words).

The design space around any object has an infinite number of dimensions and these are not the same if we consider a bouquet, a garden, a chair or a cake. We decided to explore **three expansion dimensions**, that is, three types of transformations that can be applied to one object to generate another object in the space.

- **Parametric dimension:** starting from object X, modify one or more features (e.g. colour, texture) in order to produce object X', and iteratively X'', X''' and so on.
- **Temporal dimension:** starting from object X, compute what it would look like at a different time: morning versus afternoon, spring versus autumn, now versus in five years. We applied it to garden design. It would not apply to other objects that do not change much over time, such as a chair, for instance.
- **Social dimension:** starting from object X, designed by apprentice A, and from object Y, designed by apprentice B, generate a new object that mixes the features from X and Y, as two humans combine genes when generating a child.

The choice of these axes among many possible ones came from our observation of the difficulties that apprentices encountered in their daily work, such as imagining variations of a bouquet or envisioning how a garden might evolve in the future. We explore these axes in the next sections and report on experiments that investigated how apprentices navigate along those axes.

The parametric dimension (with florists)

A flower bouquet has more features that can be modified than just the colour, which is illustrated in Figure 8-1. After discussion with teachers, we explored three more features (see Figure 8-2): the texture, the global bouquet's shape, and the spacing among flowers (Kim et al., 2021). We, therefore, use BloomyPro , a software package now used by 300 schools, developed by an eponymous Dutch company, and which graciously collaborated with us. Their platform uses a library of high-resolution 3D models of 3,877 flowers, presented individually, which allows users to assemble them in any possible arrangement.

We wanted to know how apprentices would explore this generative space around an initial bouquet. The initial bouquet (in this experiment designed by us) is placed at the centre of the left part of the screen (Figure 8-2). The apprentice may inspect a larger version of it on the right-hand part of the display, doing any 3D manipulation. Around the current design, the system proposes four new designs by changing the colour, shape, texture or spacing. If they choose, for instance, the top right one, it comes to the centre as a new 'current design' and four new variations are proposed. To avoid losing apprentices in this cyberspace, the history bar at the top lists the previous designs chronologically.

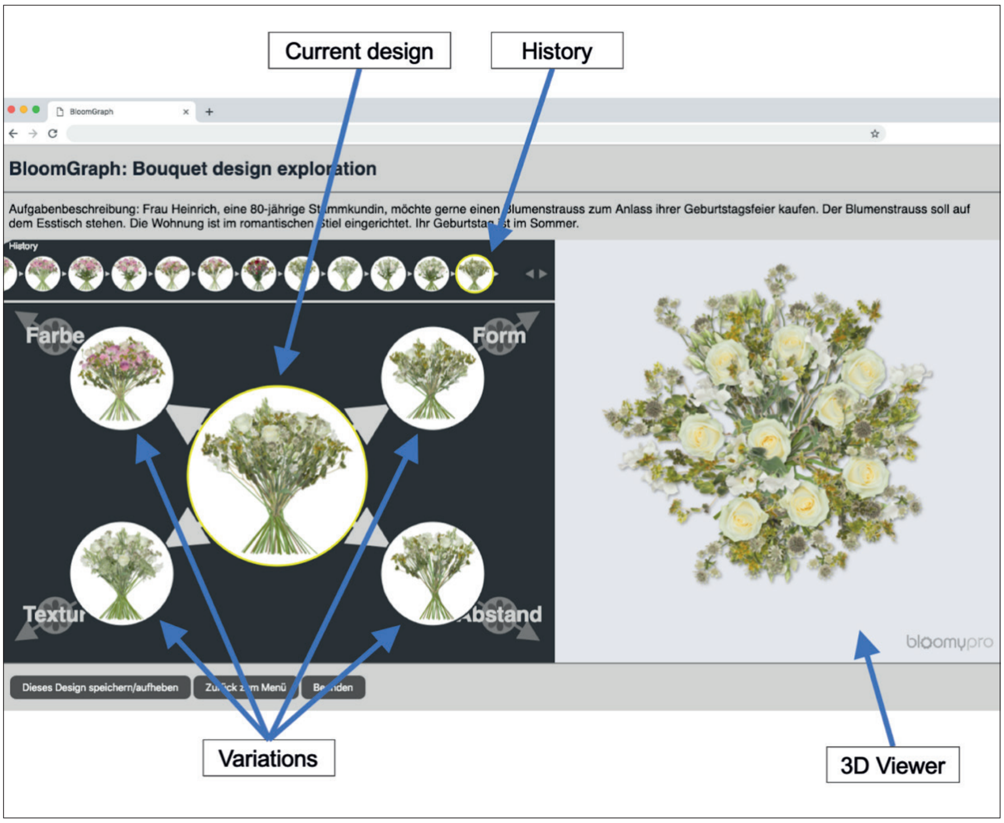


Figure 8-2 · Exploring the design space (explanations in the text) – non-linear mode

This interface proposed four directions to navigate in the design space in order to promote a structured exploration rather than some random walk. We wondered whether apprentices would feel comfortable navigating this structured but non-linear design space. We, therefore, compared it with something more familiar, a linear interface (Figure 8-3), using exactly the same set of bouquets. In this linear interface, four random variations of the current design are proposed in a linear formation. It resembles the way people go through a catalogue or the results of a search query. In order to provide an equal amount of information as in the experimental condition, each variation in the linear condition comes with a tag that shows which attributes have been changed from the current design. As with the graph condition, participants had access to their history and the 3D viewer. The difference between the two interfaces is the way we present the same data. It allows us to see if apprentices could navigate the design space through a graph interface. The short text in German at the top of the window explains who the customer is (an 80-year-old woman) and why she is buying flowers (a birthday). At the end of their exploration, apprentices had to choose the most appropriate bouquet for the particular customer.

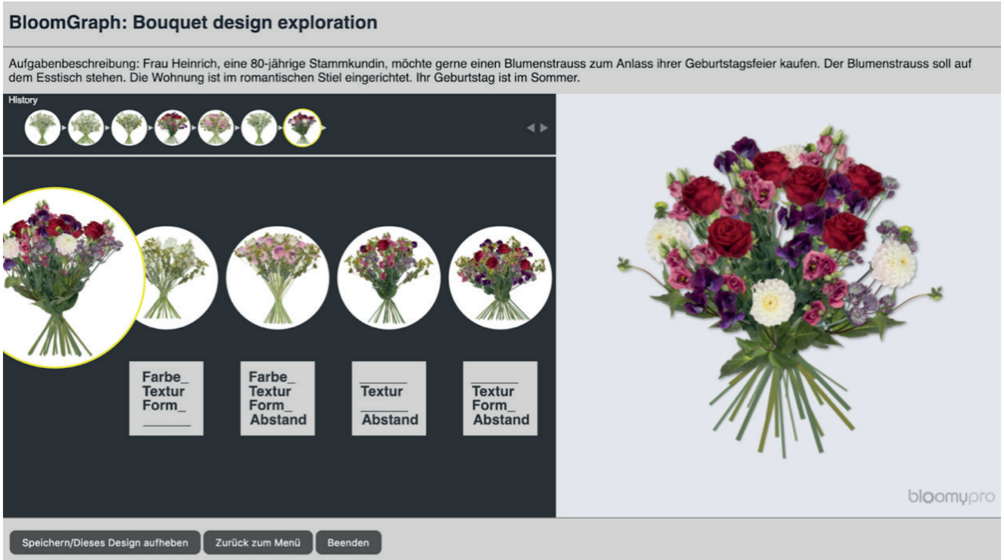


Figure 8-3 · Exploring the design space (explanations in the text) – linear mode

We compared the linear and graph navigation modes with 44 florist apprentices (43 females, the opposite of the previous studies with logisticians and carpenters). The apprentices who used the linear interface (the linear condition) explored more bouquets on average than the apprentices who used the interface with four directions to explore (the graph condition). However, we observed large variations in the linear condition. The exploration time was also significantly longer in the graph condition. Therefore, in the graph condition, participants spent more time on fewer bouquets. These results may remind the reader of our efforts to make TinkerLamp users more thoughtful. To determine whether this was the case here as well, we continued with further statistical analyses.

As always, we computed the learning gain through a pre- and post-test, but there was no significant difference. We did not really expect any difference. We were more curious about seeing how apprentices navigated using the different interfaces. For the participants in the graph condition, we compared the consistency of their navigation strategy, that is, whether they would systematically explore one dimension, for example, colour, or sometimes change the colour or the distance between flowers in a non-systematic way. The group with the higher consistency (N = 12) had significantly higher learning gains compared to the group with the lower consistency. Figure 8-4 shows the learning gains of the two groups as well as that of the linear group. The difference between the high consistency group and the linear group is also significant.

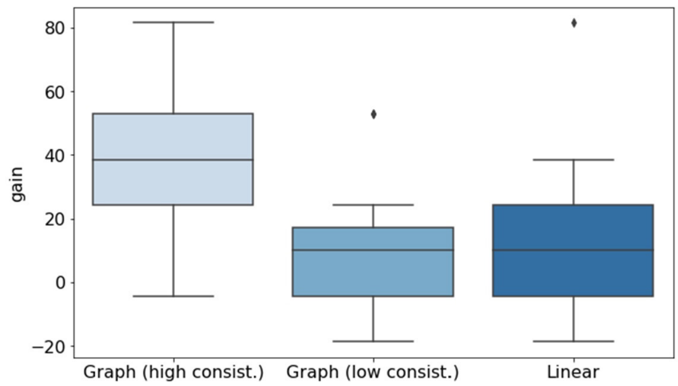


Figure 8-4 • Learning gains comparison for students with higher and lower consistency in their navigation strategy, as reported to those of the students presented with the linear mode (Kim et al., 2021)

What we conclude from this study converges with the previous observations with logisticians. Learning from an open exploratory environment is not a given. It requires some level of consistency in the exploration strategy. In the florist study, some students spontaneously appear to have had a better strategy than others. In the logistics study, we designed orchestration cards to enforce a good strategy. This has not come as a surprise for learning scientists. It is well documented (De Jong & Van Joolingen, 1998) that learning from a simulation depends upon the student's metacognitive skills and that, therefore, exploratory learning environments need to offer tools that compensate for lower regulation skills, that is, some kind of metacognitive prosthesis.

The temporal dimension (with gardeners)

There are some professions where it is not easy to undo a mistake. If your hairdresser cuts your hair too short, there is no way back. If, a few years ago, a gardener placed a tree in such a way that it casts a shadow on your kitchen, he cannot at a reasonable cost move the adult tree. These professions require a specific skill to envision how the result of the work will be not only at the end of the design process, but also a few weeks or years later for hairdressers and gardeners respectively. Both hairdressers and gardeners use tools to share their vision with their customers (pictures, sketches), but do not need tools themselves. **Professionals have accumulated enough experience to envision the future**. This is not the case for apprentices. Of course, for the first few years of their careers, the apprentices do not decide what to put and where within a new garden; they only implement the garden plan designed by their bosses. The bosses would not pay them to re-plant the same bush three times in a different place. We did, however, explore the possibility that AR enables apprentices to design a garden, viewing in 3D what it would look like in the future and modifying the garden as often as they want (Kim et al., 2021b).

In the exploration of the space of all possible gardens, we start from reality, a real garden. The difference with flowers is that it is not enough to circle them with a phone camera. Therefore, the apprentice or the teacher launches a cheap drone with a camera that systematically covers the whole garden space (Figure 8-5, left). The collected photos are fed to an online tool, such as DroneDeploy or Pix4D, which reconstructs the space in 3D (Figure 8-5, middle). The apprentice then uses a head-mounted device to walk through and explore the reconstructed space (Figure 8-5, right). The garden VR application was developed for Oculus Rift using Unity 3D software. The 3D models of the trees were created using SpeedTree, an online library in which you can buy 3D models for hundreds of plants at different growth stages and seasons.

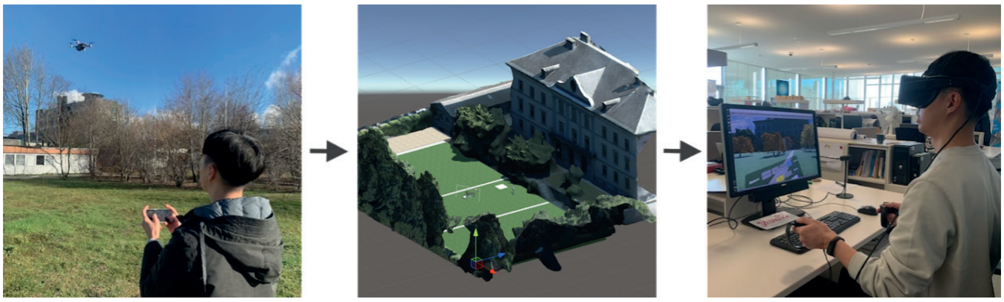


Figure 8-5 • The drone surveys the space and takes video footage (left); the 3D space is reconstructed (centre) and the apprentice immerses himself in the 3D space (right) with a head-mounted display (Kim et al., 2020).

Compared to the previous AR environments we developed, this one is immersive: the apprentice may walk in, rotate his head, look upwards or downwards; there is even a small breeze that gently ruffles the leaves of the trees. However, we have learned from the TinkerLamp story that apprentices need to step back sometimes from reality, to alternate 'heads in' with 'heads out' to promote analysis, reflections or comparisons. We, therefore, provided two modes that apprentices can switch between. The explore mode (Figure 8-6, right) is immersive; it provides an **egocentric view** where they can walk through the garden that they designed. The design mode (Figure 8-6, left) provides an **exocentric view**: apprentices see the garden from the top and can place objects such as trees in it. This exocentric perspective has been inspired by how gardeners work with drawings on paper today. By switching between the two modes, the learners can experience different perspectives on the design. As illustrated in Figure 8-5 (right), apprentices use two controllers, one in each hand. The right-hand controller can point at an object and interact with it (with a mouse click). The left-hand controller opens a menu that shows the available functions. In the design mode, the menu shows the objects that can be placed in the garden, and in the explore mode, it shows the options to explore the designed garden, including the changing seasons and trees as they grow. In the explore mode, one can also move around in the garden using the thumbstick on the left-hand controller.

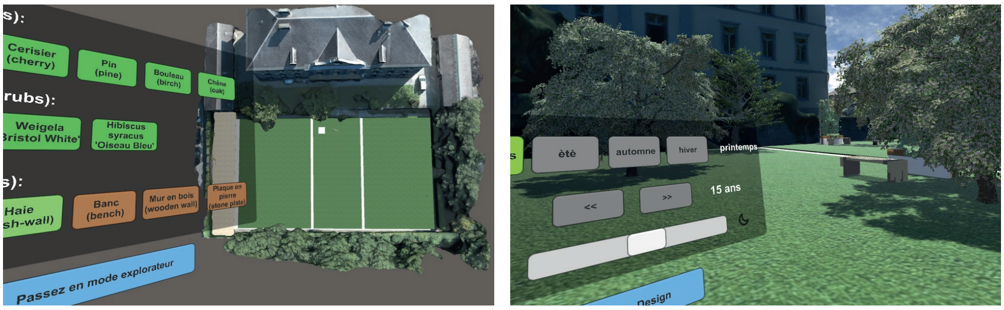


Figure 8-6 • The exocentric (left) and egocentric (right) views of a garden

The design space follows a parametric dimension: from the initial garden, apprentices can place N objects in M positions, the NM product being extremely large. But we wanted to explore the temporal dimension, that is, the possibility to simulate how the designed garden would look at different points in time as illustrated in Figure 8-7:

- **Hour:** The apprentice may change the time of the day in order to see where shadows will fall at different moments of the sun trajectory, which is important for the relative position between plants (one plant making a shadow on another one) as well as for the customer experience (shadows cast on the terrace, the balcony, the kitchen, etc.).
- **Season:** The apprentice may switch between the four seasons to visualise how the designed garden would look (winter seems a bit depressive as we did not add snow).

- **Year:** The apprentice may change the growth year, from stage 1 to 5, which is also as important for the plants as for the building. This provides them with an imperfect representation of what a professional would visualise.

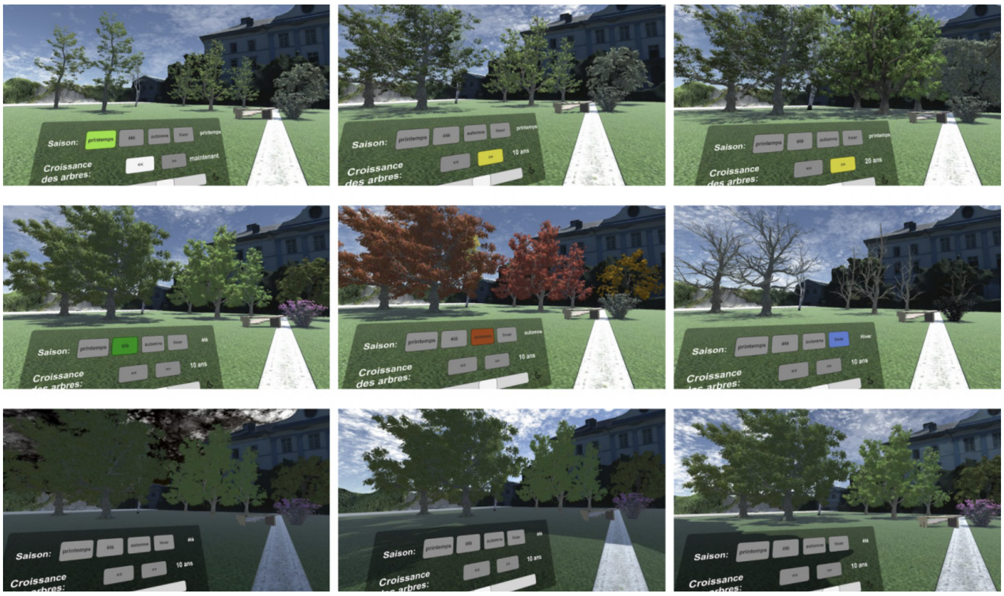


Figure 8-7 • Navigation in time: Changing the hour of the day (bottom row), the season (middle row) and the garden age (top row)

These time navigation features illustrate the conclusions of the previous chapter: a pedagogical interest of AR applications is to **make the impossible possible**. Nobody is able to move the sun (changing hours), change the season or fly to the future! It is not about imitating reality, even though the AR has some visual realism. But it is about **escaping from reality**.

This only makes sense, of course, if there is a learning gain for apprentices. We conducted an experiment with 30 gardener apprentices (26 males) from two VET schools. Considering the relevance of the task to the curriculum, we only recruited students who were specialising in landscaping, but not in plant production. We also limited our sample to the second-year students in the three-year curriculum for the homogeneity of the population. They have learned design rules for gardening for two semesters but have limited experience in designing gardens themselves. We compared their digital design (Figure 8-8, right) with the traditional pen and paper designs (Figure 8-8, left) in a within-subjects experimental plan: 14 designed a garden on paper first and then on VR, and 16 followed the process the other way around to counterbalance the order effect.

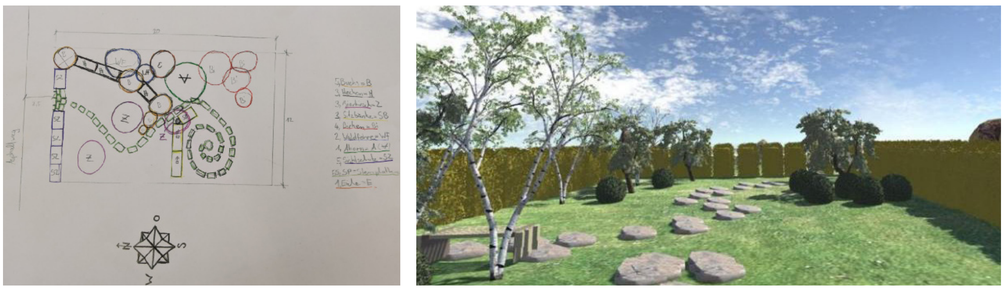


Figure 8-8 • Two modes of garden design: pen and paper versus AR

We asked two gardening teachers to rate the quality of the designed gardens based on three criteria they proposed: composition, proportion and creativity. The statistical analysis revealed interesting results: (1) there was no significant difference with respect to the 'composition' criterion, (2) VR designs received better grades in terms of 'proportion' and (3) pen and paper led to more creative designs. However, when analysing the order effect, drawing first on paper before using AR produced significantly better designs on the proportion and composition criteria. When using AR in the second part, apprentices spent significantly more time in the exocentric view and the percentage of time on this exocentric view was significantly correlated (.426) with the design quality. That is a very interesting finding for two reasons: The first is that since the paper drawing is even more 'heads out' than the AR exocentric view, the combination of both seems to have significant effects, which confirms our findings with the logistics simulation.

The second is that we tend to compare the performance of digital tools with the use of classical paper-based methods, used as the baseline practice. This comparison addresses the question that every teacher, school director or decision-maker generally asks us. But in daily practice, there is no need to oppose paper and digital. This book is replete with stories that precisely illustrate their complementarity.

The social dimension

The two previous sections presented ways to digitally explore the design space for their productions. Now, imagine that 20 gardeners design a garden on paper and the teachers put them all on a wall. This wall would also provide some interesting visualisations of the design space. The teacher could ask the apprentice to redesign a garden that combines two of the displayed designs. We built an application, on the top of the garden VR, by which two or more designed gardens can be combined. A few years ago, a lab member contributed to DeepArt, a popular website, where you could upload one picture and select a famous painting, and the system would apply this painting style to your picture, your dog, for instance, being revisited by Dali. This re-painting was achieved by using machine learning methods called deep neural nets. We used a simpler method that extracts key features from two AR-designed gardens and recombines them (Kim et al., 2022). This method is called a 'genetic algorithm'. It is used in AI to explore design spaces. We extract the DNA of each garden as a tree structure composed of objects (plants, stones and so on), their position and orientation. When combining two gardens, the algorithm combines genes using genetic operators, such as mutation and crossover. Multiple applications lead to multiple 'children', as illustrated in Figure 8-9. We do not want to get into technical details here, but the elegance of this algorithm is worth mentioning.

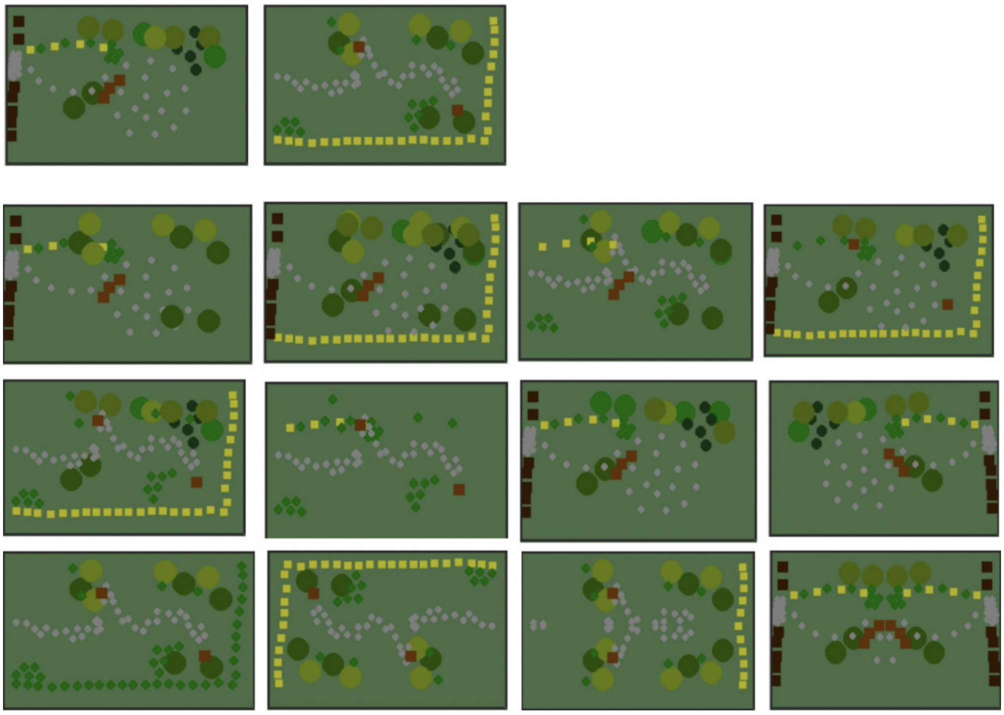


Figure 8-9 • From the two garden 'parents' in the top row, the algorithm extracts their DNA and recombines them through various genetic operators to produce, for instance, any of the 12 gardens below them.

The process is explained in Figures 8-10 and 8-11. As this experiment was conducted during the pandemic crisis, we used only online technologies – no head-mounted displays. First, the apprentice – let us call him Louis – designs his garden (Figure 8-10, top) in the same way as in the exocentric view of the Garden AR. Once Louis is satisfied with his designs, he can move on to the next phase. Louis' garden then appears in the social design space graph, the left grey box of Figure 8-10 bottom image, where he can see the gardens designed by his peers, Philip and Kevin. This graph represents which gardens are created by combining the two other gardens. The process of selecting and combining two gardens to generate new ones is demonstrated in Figure 8-11. Louis can select two designs from the design space graph and, using the design mixing generator, with the grey box in the middle, he can generate new designs. The 3D visualisation of the garden is shown on the top right of the interface. He can use the slider to get other variations. Louis can repeat this operation many times. When he is satisfied, he pushes the 'Add selected design to the design space' button and the new garden appears in the social graph. It can then be selected and combined with another garden design. This process can easily be described by keeping the genetic metaphor: the user selects two 'parents' in the social graph. It describes how much genetic material from each parent will be transmitted to their child and, if the apprentice is satisfied with his selection criteria, the child is added to the social graph.

Figure 8-10 · Interface for designing a garden online (top) and exploring new gardens (bottom)

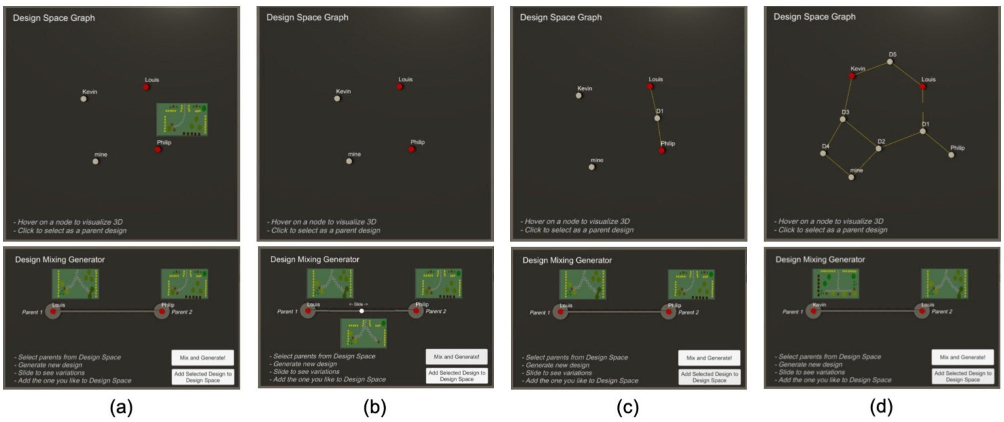


Figure 8-11 · Zoomed-in view of the interface showing the process of generating new designs

Based on our previous experiences working with garden-designer instructors, we knew that this application was unlike other tools being used in the garden design curriculum. This meant there was a valid threat of this application not being adopted by instructors because of it being too novel or foreign to their current practices. To address this concern, we recruited six garden design instructors from vocational schools to take part in a semi-structured, task-based interview about the application. The goal of the interview was to learn more about the feasibility of using it in an authentic educational setting with apprentices and to investigate whether it could support the students' divergent thinking. All of the instructors reported that it was intuitive and easy to use, and all were open to incorporating it into their courses. They also said the design mixing process would 'help to open the minds' of the apprentices and support their divergent thinking, helping them develop a valuable skill for their profession.

Following the interviews with instructors, we conducted a controlled online experiment with novices to compare design space exploration with design mixing to two other conditions, one with no exploration and the other with random exploration. The no exploration condition provided a baseline for the comparison. The random exploration condition provided users with randomly generated garden designs without the interface of design mixing. The participants first designed a garden and explored the design space using a given interface for each condition. Then they had a second chance to create a design. We were interested in two measures – creativity support of the tool measured by the Creativity Support Index (CSI) survey and the novelty of the design outcome measured by the difference between the initial and the final designs. As a result of the experiment, we found that design mixing can provide significantly more support for novice designers, particularly for the exploration and collaboration factors. We also observed that the participants could produce more novel designs after using the design mixing functionality. Finally, we showed that making it easier for novices to explore and keep track of many ideas directly affects the novelty of the designs they produce. Our results show the importance of scaffolding creative exploration for novice designers and demonstrate the feasibility of using social design mixing for this purpose.

So what?

The AR/VR environments described in this chapter and previous ones enable interactions that do not exist in reality, such as manipulating four shelves with two fingers or seeing forces that are normally invisible to human eyes. The current chapter went one step further in taking freedom from reality by allowing apprentices to move trees, change seasons, jump into the future and having two gardens give birth to a baby garden. We stressed that these differences with reality may be pedagogically more interesting than adherence to reality. However, some degree of realism is also required to connect the apprentice to the reality of their work. The point of escaping reality is not to be fancy or original. The goal is not to facilitate manipulations for the sake of manipulation. **The pedagogical rationale for escaping from reality is to engage apprentices in cognitive activities that produce learning effect**s, as we test in all experiments.

Does the pedagogical value of these AR/VR environments go beyond the simple WOW effect? Yes, there is a wow effect; we are not naïve about it. Per se, this wow effect opens doors: as all our empirical studies require convincing teachers and directors to invest some of their precious time with us, it is not a negligible asset. Also, it helps stakeholders to gain a broader understanding of learning technologies or EdTech: they can be much richer than an application or website with texts, quizzes and video lectures. It is not a crime if teachers and apprentices get excited by some novel school activities. Of course, the novelty effect does not last very long. What these three last chapters reveal is how to transform this initial engagement into learning outcomes. Being engaged, manipulating and exploring is not enough; being over-engaged can even be detrimental. This is true for the random rapid redesign of warehouses as well as random exploration of the design space for gardeners. For our AR applications, the experiments reveal the need to articulate action and reflection, exploration and abstraction, comparisons and predictions. Apprentices are like us: they do not spontaneously engage in these reflective activities. They need to be prompted either by the learning environment itself, as in the exocentric view of gardens, or by the teachers, as in TinkerLamp. Moreover, it is not a trivial exercise for teachers to scaffold this reflection phase, as their interventions with the apprentices' contributions need to be built up in real-time. Therefore, teachers also need to be supported by the technology, as in the TinkerLamp dashboards. Down the road, none of these tools will generate stable formal knowledge without a well-orchestrated debriefing session driven by the teacher. **There is a time for telling**.

Chapter 9
VET analytics

Richard Lee Davis, Son Do-Lenh, Mina Shirvani Boroujeni, Ramtin Yazdanian

This book highlights a variety of digital technologies developed during the Dual-T project, from AR to social networking platforms. One of the features that these technologies had in common was that they generated new kinds of data. In some cases, these data were fine-grained traces of individual students' activities. In other cases, these data provided higher-level perspectives on entire VET institutions or groups of institutions. We believe that these data were an essential part of the digital technologies we were developing and we devoted considerable effort to figuring out ways to utilise these data in our work.

Most of these data could not be easily analysed or understood with standard statistical methods. Making sense of these data necessitated a turn to the world of learning analytics. Learning analytics is an interdisciplinary approach that brings together methods from machine learning to data mining to statistics to HCI. A widely-used definition of learning analytics is 'the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimising learning and the environments in which it occurs' (*https://tekri.athabascau.ca/analytics/*).

Learning analytics can be used to help meet a variety of objectives, including monitoring and analysing learners' activities in order to gain a better sense of what is happening in the classroom, making predictions about students' performance to identify and support those who need extra attention, assessing what students know and using this as a source of feedback to aid students in their studies, and personalising and adapting instructions to students' needs. Some of the methods used to meet these objectives include predictive modelling (e.g. regression), social network analysis, clustering, and data visualisation (readers interested in a more extensive treatment of the objectives and methods of learning analytics in the literature could look to Baker (2010), Chatti et al. (2012) or Clow (2013).)

This breadth of methods and objectives can be overwhelming, and a number of taxonomies have been proposed for categorising and organising learning analytics. One that we found to be both simple and useful was developed by Chatti et al. (2012). This 'reference model' suggests that learning analytics projects can be organised according to four questions: How? What? Why? Who? Any given project uses a specific set of methods (How?) on a dataset (What?) to achieve some objective or answer some question (Why?) posed by stakeholders (Who?). This reference model is helpful when trying to organise and make sense of the different types of analyses that fall under the umbrella of learning analytics. It is also useful in setting a boundary around the field of learning analytics. For example, if the answer to 'Why?' does not directly relate to student learning, it is not learning analytics. Likewise, if the answer to 'Who?' includes people from outside the formal educational system, such as managers in a company, it is not learning analytics.

Practically, this means that many of the ways we have used data in the Dual-T project do not technically fall under the umbrella of learning analytics. One of the points of this book (and the Dual-T project) is that the vocational education system, especially the dual vocational system, is uniquely different from other education systems. It has different objectives, stakeholders, and forms of assessment and evaluation, and it is distributed across multiple sites. Just as these differences need to be considered when designing and implementing digital technologies for VET, they must also be considered when developing analytics tools and methods. For this reason, we have coined a new term that describes our work: VET analytics. VET analytics is the measurement, collection, analysis and reporting of data from *the entire VET system* for the purposes of understanding and optimising *all aspects of vocational education and training*. This is a more expansive definition, which encompasses a larger group of stakeholders (e.g. apprentices, administrators, instructors, in-company trainers, employer associations) and a larger set of outcomes (e.g. communication patterns between stakeholders, feedback patterns related to learning documentation, changes in the types of skills valued by industry).

The VET system and the world of industry are deeply interconnected. Employer associations play an important role in shaping the curriculum so that students learn skills which are relevant to their industries, and industries take on some of the responsibility of training students through apprenticeship programmes. This means that a narrow focus on student learning in the classroom is not appropriate for VET. While this narrow focus might improve students' understanding in the classroom, it ignores the many connections to points outside of the classroom which are essential to VET. For example, this narrow focus ignores whether the things being learned in the classroom connect meaningfully to the students' apprenticeships and fails to consider whether the things students are learning are relevant to future employers. VET analytics takes all of these factors into account. Its focus is not only on improving student learning, but on optimising the entire VET system.

We illustrate VET analytics with three vignettes.

In the first vignette, we describe how learning analytics was the key to unlocking the pedagogical value of the TinkerLamp. The story of the TinkerLamp has been told in rich detail in Chapter 6, but there the emphasis was on the co-development of the technology with VET stakeholders and the importance of integrating classroom orchestration tools with the platform. Here, we focus more on the TinkerBoard, the data visualisation dashboard which was the key to unlocking the pedagogical value of the TinkerLamp system in the classroom. This vignette illustrates the value of 'closing the loop', that is, using the data captured by digital technologies as a source of feedback which helps to ensure that the technologies are being used effectively. Closing the loop turns out to be of central importance in all three vignettes, and the importance of closing the loop is one of the key takeaways of this chapter.

In the second vignette, we talk about Mina Shirvani Boroujeni's analysis of communication patterns between instructors, in-company trainers and students on the Realto platform. This analysis identified dysfunctional communication patterns between the different stakeholders in the VET system, in particular how instructors and in-company trainers were not reliably responding to students' requests for feedback. The more we investigated this issue the more we realised that it was a widespread problem. It was also present on e-DAP and LearnDoc, online platforms we had developed for chefs and bakers respectively. Together with Christian Gianneti, we attempted to address this problem by setting up workshops for in-company trainers to show them the value of providing timely feedback to apprentices on the e-DAP platform (see Chapter 3) or by introducing them to Realto in the workshops that all three stakeholders attended together (see Chapter 4).

The third and final vignette focuses on the skills that students learn during their training. The VET system is designed to provide students with skill sets that prepare them to be effective and productive employees. In Switzerland, these skillsets are formalised in training plans which are updated every five years in consultation with regional and national industry organisations. This is a top-down approach to keeping the VET curriculum in line with the needs of industry. However, we realised that new forms of data had made it possible to pursue a bottom-up approach. Over the past decade, large numbers of online job ads had been collected across a variety of professions, including most VET professions. We extracted the skills from the plain text of each job advertisement and used this to track the rise and fall of in demand skills in the labour market. We then used this data to build a predictive model of which skills were most likely to emerge in the coming years. Our work on this project is ongoing, but we believe that when this information is used to close the loop and help design future curricula, it will make the VET system more responsive to the needs of the labour market.

The TinkerBoard Story

In Chapter 6 we introduced the TinkerLamp, a tangible, an AR system for teaching apprentice logisticians about storage optimisation. There was an aspect of that story that we only touched on briefly, but which deserves more attention for what it can teach us about VET analytics. This is the introduction of the TinkerBoard to the TinkerLamp system.

The TinkerBoard is a data visualisation dashboard designed by Son Do-Lenh which is meant to be permanently projected on a wall for the duration of the TinkerLamp activity. It is an interactive system which collects, processes and displays information while also providing the teacher with the ability to manipulate the display of information and control the TinkerLamps. In the following paragraphs, we re-introduce the TinkerBoard by telling the story of how Jacques Kurzo used it in his teaching. For a more complete overview of the TinkerBoard, see Chapter 6.

Jacques had split the class up into four groups and assigned each group to work with a TinkerLamp. After a brief introduction, the students began to create and test different warehouse layouts. Jacques walked around the classroom, answering questions and offering help to the different groups. Once the groups had created and tested five warehouse layouts, Jacques hit a button on the TinkerBoard to pause all the lamps. Freezing the simulations helped to bring the students' attention to the front of the class, where Jacques was standing next to the TinkerBoard projection (see Figure 6-9 in Chapter 6).

In front of the class, Jacques selected one layout from each group and added them to the ComparisonZone of the TinkerBoard. Presented under each layout were statistics about the gross area, the gross storage area, the net storage area, the number of shelves, the degree of surface utilisation and the average amount of time it took to move a palette to or from the shelves. Jacques led a discussion about each of the different designs, pointing out their strengths and weaknesses in terms of these statistics. This allowed him to clarify the meanings of the different terms, many of which were new to the students, and helped him explain the trade-offs between maximising utilisation of space and minimising the average time per palette by contrasting different groups' designs. The TinkerBoard made it easier to ground the explanation of the optimisation problem in the students' actual designs, and by contrasting different examples, Jacques was able to point out design strategies and heuristics that students could use to better optimise their layouts.

Recall that the TinkerBoard was developed to solve a problem: students in VET classrooms were not making connections between the TinkerLamp activity and the concepts the activity was designed to teach. To determine whether the TinkerBoard had solved this problem, we designed an experiment with four classrooms taught by two different teachers. Since we have already explained the details of this experiment in Chapter 6, we will only provide a quick overview here.

Some of the students worked with the TinkerLamp+TinkerBoard while others worked only with the TinkerLamp. When we evaluated the students' conceptual understanding and their ability to solve a warehouse layout problem, we found that the students who worked with the TinkerBoard scored higher on both (see Table 6-1 in Chapter 6).

Why tell this story in the context of a chapter on VET analytics? **Because it emphasises the value and importance of data**. The data being captured and generated by the TinkerLamps were the key to unlocking their potential to help students learn. Until the introduction of the TinkerBoard, data were being collected but not being used during the classroom activity. The TinkerBoard transformed this raw, dormant data into informative, interactive visualisations that were used by teachers and students during the classroom activity.

One of the main explanations for why the TinkerBoard supported learning in this way is that the TinkerBoard 'closed the loop'. In other words, the TinkerBoard provided a feedback mechanism that both the teacher and the students could use to monitor and control the classroom activity. At various points during the classroom activity, the teacher checked the LayoutHistory panel of the TinkerBoard to view all of the groups' real-time activities and used this information to identify groups who needed special attention (Figure 9-1). The students also regularly consulted the TinkerBoard during the activity to compare their work to those of the other groups and used this information to modify and improve their own layouts (Figure 9-2). Both the teacher and the students used the information displayed on the TinkerBoard to keep the activity on track and to ensure that the TinkerLamps were being used optimally.

Figure 9-1 · The teacher consulted the TinkerBoard during the classroom activity to see the students' work simultaneously.

Figure 9-2 · Students regularly consulted the TinkerBoard during the classroom activity.

The TinkerBoard also helped the teacher connect the TinkerLamp activity to the discussion about optimisation. The TinkerBoard made it easy to use the students' layouts as examples when explaining the trade-offs between maximising utilisation of space and minimising the average time per palette. This helped ground the concepts from the discussion in the students' experiences, transforming it into a 'time for telling'.

We designed the TinkerLamp system to enable rich interactions before realising that the TinkerLamp data were actually a central part of the technology to be pedagogically exploited.

When digital tools are brought into classrooms, there are many ways that things can go wrong, and a few ways that things can go right. The added complexity can make it challenging for the teacher to monitor whether the students are using the tools as intended, and harder for students to see what their peers are doing. In the case of the TinkerLamp, the teachers and students could easily see the current warehouse layout of each group thanks to the tangible shelves, but the information contained in the projected simulation was harder to see, and there was no way to see the history of what different groups had tried. However, all of this information was contained in the TinkerLamp data. The TinkerBoard transformed this data into a public, interactive visualisation that restored everyone's ability to monitor and make sense of what was happening in the classroom, and this restored ability is what helped ensure that the activity remained on track and that students learned.

This story illustrates an important point that is especially relevant for the designers of learning technologies: Teachers and students need help managing the complexity that digital tools introduce, and the data that these tools generate is key to this. The data should not merely be treated as something to be analysed later by researchers or developers. Instead, the data should be used to show the teacher and students what is happening, what has happened and what might happen. When the data is used in this way, it acts as a feedback mechanism that teachers and students can use to ensure that they are using the tools correctly. In this chapter, we call this way of using data 'closing the loop', and we will see the importance of this idea in each of the stories.

The Story of Social Network Analysis

Realto was developed to make it easier to capture, share and manipulate experiences occurring in the different sites of the dual VET system (internship workplace and classroom). A core mechanism of Realto is the ability of teachers in the classroom and in-company trainers in the workplace to view, evaluate and give feedback on these experiences. When all is working well, these interactions allow information to flow more easily between the different sites, which makes it possible for teachers and in-company trainers to align the topics they teach (see Chapter 2 on the Erfahrraum model for more on this).

All of these interactions between stakeholders are preserved in the data collected by Realto. Every action, such as a student's request for feedback, an in-company trainer leaving feedback or someone liking or commenting on a post, is saved by Realto in its log files. We realised that this data could provide us with a way to model the entire Realto network. To do this, Mina Shirvani Boroujeni created a network analysis module within Realto (Boroujeni, 2018). This module automatically constructed graphs, where each stakeholder was represented as a node and the edges between the nodes represented different kinds of interactions. Figure 9-3 shows an example, a sub-network with nodes for apprentices, in-company trainers and teachers, and the directed edges representing communication between stakeholders.

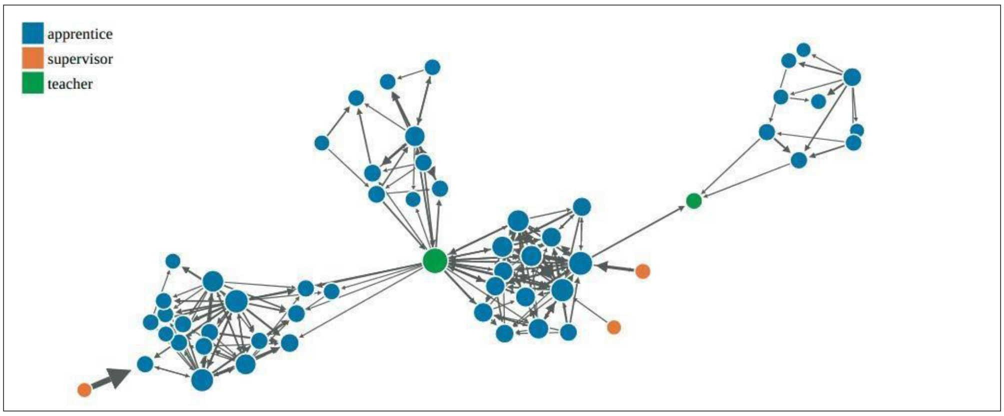


Figure 9-3 · Example of Realto sub-network of florist teachers, in-company trainers and apprentices

Was Realto actually helping to make connections between stakeholders and bridging the different sites of the VET system? To answer this question, we analysed four sub-networks containing connections between (1) apprentices, (2) teachers and apprentices, (3) in-company trainers and apprentices and (4) apprentices connected to both a teacher and an in-company trainer. We found that 80% of the apprentices using Realto had a connection with another apprentice, 47% of the apprentices were connected with a teacher, 26% of the apprentices had connected to an in-company trainer, and only 1% of the apprentices had connections with both a teacher and an in-company trainer (see the column apprentices count in Table 9-1 in the appendix).

Although these percentages suggest that many of the apprentices using Realto were not interacting with their teachers or in-company trainers, they do not capture the whole story. For example, interactions between teachers, students and in-company trainers that occurred offline were not observable in the Realto data. We were aware of many connections of this type, which were made outside of Realto and were not captured in these statistics.

However, there was a statistic that we took seriously. This was binary reciprocity. Binary reciprocity is a number between 0 and 1, which captures the proportion of two-way connections in a graph. If an apprentice posted their learning documentation and asked a teacher or an in-company trainer for feedback, that would be picked up as a one-way connection. If the teacher or the in-company trainer then provided feedback to the student, the request plus the response would be picked up as a two-way connection.

In our analysis, we found that binary reciprocity was below 0.5 in all cases (Table 9-2). This was a concerning finding: in all cases, communication between stakeholders was more likely to be one-way than two-way. This means it was more common to reach out to someone and not get a response than to get a response. This was particularly concerning in the context of learning documentation. In the Swiss VET system, apprentices are tasked with documenting their learning experiences and connecting them to a list of competencies. One of the requirements for receiving a diploma is to submit this learning documentation. Getting the learning documentation right is tricky for apprentices, and feedback from their in-company trainers and instructors is of enormous help. In fact, in-company trainers are required by federal regulations to give feedback on this learning documentation at least once a semester. Our findings about binary reciprocity on Realto suggest that apprentices are seeking out this feedback, but that instructors and in-company trainers often fail to provide it within Realto.

Figure 9-4 shows graphical representations of these communication networks. One-way connections are represented with a single-headed arrow, and two-way connections are represented with double-headed arrows. The infrequency of double-headed arrows provides a visualisation of the infrequency of reciprocal communication on Realto.

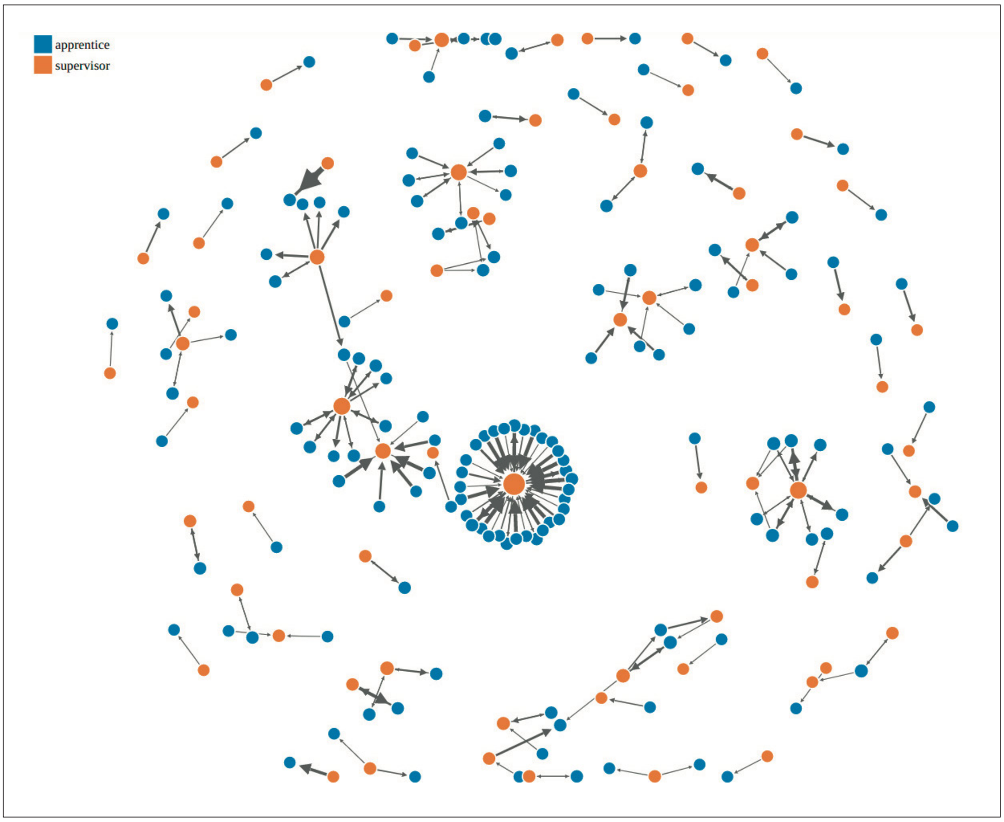


Figure 9-4 · In-company trainer-apprentice communication sub-network. The direction of the arrows indicates the direction of the interaction (e.g., from apprentice to trainer), and the boldness of the arrows indicates the numbers of interactions between two people.

This finding was upsetting, but it was not the end of the story.

A similar situation was playing out with bakers and chefs. Each of these professions has its own learning documentation platform which they use instead of Realto (bakers use a platform called LearnDoc and chefs, a platform called e-DAP). Both were created as part of the Dual-T project and predate Realto by several years. The bakers and chefs continue to use these platforms instead of Realto because they were designed specifically for their professions and because they satisfy their needs and work properly.

While neither LearnDoc nor e-DAP have a network analysis module like the one built into Realto, it was nevertheless possible to directly analyse the log files to investigate what kinds of feedback the in-company trainers of the chefs and bakers were giving. As with Realto, we found that many of the in-company trainers were giving little to no feedback to their apprentices on the platform. And as with Realto, this was concerning because soliciting and receiving feedback from in-company trainers was one of the main reasons that the e-DAP platform was developed.

A potential solution to this problem was found by Christian Gianneti, a former chef and in-company trainer and now a full-time teacher. In 2019, Christian invited the in-company trainers to a workshop where he demonstrated how e-DAP could be used to provide feedback and emphasised the added value of providing feedback on the platform.

Continued monitoring of the log files showed that two things began to change around this time. First, both the number of feedback requests from students and the number of responses from in-company trainers increased dramatically, reaching their highest levels in nearly a decade. Second, the average amount of time between an apprentice's request for feedback and the response from an in-company trainer decreased to its lowest point on record (see Figure 3-8 in Chapter 3).

An analogous effect was seen with Realto-based on the way the training workshops were organised (see Chapter 4). The amount of learning documentation filled in by the students was considerably higher and more sustained when all the stakeholders participated in the same training session in contrast to the case when training was done separately. As we saw in Chapter 3, apprentices using the e-DAP platform in 2020 reported higher feelings of connectivity between the school and the workplace than apprentices who did not use the platform. Although we cannot say for sure, the positive changes in feedback given by in-company trainers likely contributed to these apprentices' feelings of connectivity.

This story illustrates two points. The first is one we have already encountered, which is the importance of using data to close the loop. Analytics are essential if the goal is to successfully integrate digital technologies into VET. Unless there is a good reason, the data produced when stakeholders use digital technologies should be leveraged to ensure that the tools are being used optimally. The second point is about the value of VET analytics. In this account, we showed how analysing data from the school, the workplace and the intercompany courses uncovered serious problems, and pointed towards ways to address these problems once uncovered. A purely learning analytics approach would most likely have missed these problems since it would not have considered data from outside the school. The VET system is fundamentally different from other educational systems, and this story shows the importance of using a specially tailored analytics approach to better understand what is happening in all parts of the system.

The Story of Emerging Skills

Our third and final story is about the potential of VET analytics to inform and globally shape the entire VET system. The primary purpose of the VET system is to provide students with skills and expertise that will enable them to take on a skilled labour job immediately upon graduation. There are two sides to this equation. The industries that require skilled workers have job openings that they hope graduates of the VET system will be equipped to fill while the VET system trains students with specifics skills that they hope will be in demand once they graduate. Keeping this equation balanced requires both industry and the VET system to coordinate with one another. In Switzerland, this coordination occurs every five years when the heads of the VET system meet with the regional and national industry organisations. During this meeting, skillsets are formalised into training plans that will determine curricula across the VET system.

This is a top-down approach to steering the VET curriculum. Stakeholders with experience and influence make informed predictions about the future needs of industry and adjust the VET curriculum to meet those needs. This is a valid approach, one that has been working for decades, but it has shortcomings that should not be overlooked.

One of the more obvious shortcomings is that the five-year update cycle may be too slow. This is especially true today, with the AI-powered fourth industrial revolution in full swing. The dramatic increase in automation and the rise of new technologies has rapidly transformed the skillsets required for a wide variety of jobs and industries. Highly valued skills have fallen out of favour while new skills have risen to prominence. These changes can occur rapidly, creating a situation where students in the VET system are stuck learning outdated skills or fail to learn skills that are now in high demand. One solution to this problem would be to increase the frequency with which the VET curriculum is updated, but there is still a problem that this approach would not solve.

That problem is predicting the future. The industrial landscape is complex, and it is not so easy to predict which skills will be valuable in years to come. For example, few would have predicted that bankers would need to understand peer-to-peer networking, cryptographic hashing or public ledgers, but these are precisely the concepts involved in something which has profoundly altered the landscape of banking over the past decade: Bitcoin and other forms of cryptocurrency. This is the kind of change that few people would have seen coming, regardless of their level of expertise or influence.

One possible way around these shortcomings is to introduce a bottom-up approach into the process. This kind of approach would also provide the VET system with information about future skills, but this information would be directly derived from the labour market. Ramtin Yazdanian explored the feasibility of this approach in his PhD (Yazdanian, 2021). His approach was to train predictive models on labour market data to predict emerging skills. There is a lot to unpack in that sentence, so let us take it term by term.

First, what is a predictive model? Predictive modelling is a method that uses statistical models trained on historical data to predict future outcomes. A simple example of a predictive model is a line fit to data. Maybe you want to try and predict what your favourite basketball team's final score will be while you are sitting through commercials at halftime. You could plot the score on the y-axis and the time on the x-axis, and then fit a line to the data. Extend the line out to the end of the fourth quarter, and it will sit directly on a prediction of the final score. While this method is simple, it is not usually accurate. There are more sophisticated methods that can produce better predictions, but these often require large amounts of data to be effective.

Ramtin was able to use these more sophisticated methods because he found an enormous, and largely untapped, source of labour market data: job ads. For the past 10-15 years, companies have been posting job advertisements on websites such as monster.com and linkedin.com. These sites possess huge archives of historical job ad data, and these archives contain information on the dynamics of skills in the labour market. Ramtin's hypothesis was that predictive models trained to learn these dynamics should be able to predict the rise and fall of skills in the labour market.

However, simply predicting the rise and fall of skills was not the main outcome of interest. Recall that the goal of this work was to predict which skills would be in demand when apprentices were leaving the VET system and entering the labour market. Ramtin called these emerging skills and defined them as 'previously low-demand skills that have recently experienced a surge in hiring demand'. Successfully predicting emerging skills from historical data is exceptionally challenging because they are largely indistinguishable from other low-demand skills that never emerge.

As a proof-of-concept, Ramtin developed a predictive model to identify emerging skills in the information technology sector. He began with a dataset of job ads, where each ad was represented by the list of skills it contained. He used this data to create a time series of each skill's popularity in the labour market and extracted hundreds of features from these time series. These features include summary statistics (e.g. mean, various quantiles, variance), linear trends, measures of non-linearity and spikes and FFT coefficients. The most informative features were identified using a combination of methods and brought together into a single logistic regression model. (The full technical details of this model can be found in Yazdanian et al., 2022.)

Ramtin found that predicting emerging skills was, in fact, possible. His best model was able to consistently beat a number of strong baselines, showing that job ad data contain enough information to predict many of the skills that will emerge in the future.

Although this had worked on data from the IT sector, it was not obvious that it would also work in VET domains. The IT sector moves at a breakneck pace, with new programming languages, technologies, frameworks, and platforms being introduced every day. Needless to say, a VET domain such as masonry does not experience such rapid change.

So what happened when Ramtin applied his method to job ad data from VET industries? The results were not as clear. He used his method on job ads from two VET sectors: logistics and healthcare. In some cases, his model was able to produce useful predictions, but in other cases, his model failed. One of the most likely reasons is that this method, which was developed on data from the IT labour market, is ill-suited to the VET labour market. We saw a similar issue in the story about social network analysis. There, Mina's methods, which she developed using MOOC data, did not work when applied to data from the VET domain. In her case, it required developing new methods that were specifically tailored to VET. A similar approach is probably needed in this case as well. Rather than dismiss Ramtin's results as a failure, we see them as reminding us, yet again, that VET is a unique domain that requires its own special methods and approaches. With persistence and luck, we (or someone else) will find a way to use job ad data from the VET labour market to help predict the skills that students will need once they graduate.

What is the moral of this story? There are two. First, this story illustrates why VET analytics must have a wider scope than learning analytics, which is solely concerned with optimising student learning. Optimising student learning is important. However, in the VET system it is also important to make sure that the skills that students are learning will be in demand when they graduate. In other words, the curriculum also needs to be optimised. A learning analytics approach would optimise student learning while not concerning itself with the content in the curriculum. Over time, this approach would produce apprentices with excellent, but obsolete, skills. The wider scope of VET analytics avoids this by respecting the complexity and interconnectedness of the VET system.

The second moral of this story is one that you may be sick of by now. This is the importance of using data to close the loop and ensure that things are working as intended. In this account, the loop is at the most zoomed out, macro level, and the technology in question is the entire VET system. If we are ever able to use the data generated by the VET system (labour market data) to help make predictions about which skills are likely to become important in the future, this will close one of the many loops in the VET system. This, in turn, will help make VET more agile, ensuring that apprentices graduating from the system have more relevant skills.

So what?

If there are only three things that you take away from this chapter, let it be these:

First takeaway: VET analytics is a novel approach that embraces the complexity of the VET system. The Story of Emerging Skills shows why a learning analytics approach that focuses on student learning while ignoring other aspects of the VET system is inappropriate. The different parts of the VET system have deep connections that tie them together. The things that students learn in the classroom are determined by a curriculum that was designed to meet the future needs of companies. Optimising for student learning without also optimising the curriculum makes no sense within the VET context. VET analytics is built on an understanding of the complexity and interconnectedness of the VET system, and recognises the need to consider multiple stakeholders, contexts and outcomes.

The Story of Social Network Analysis also illustrates this idea. To see why, we must provide a bit more background. Mina pioneered her methods on data from a MOOC (Boroujeni, 2017). However, she was unable to directly apply these methods to the Realto data due to differences between the structure of MOOCs and that of the VET system. She needed to modify her methods to account for the differences in stakeholders, forms of social interaction and communication patterns. Again, this illustrates the unsuitability of existing analytics approaches and the need for a new approach that understands and embraces the complexity of VET.

The TinkerBoard story showed that methods from learning analytics still have a central place in VET analytics. This story showed how introducing a data visualisation dashboard into the classroom helped to ensure that the TinkerLamp was having a positive impact on student learning. This was a straightforward, effective use of learning analytics in a VET classroom. This story is a reminder that VET analytics has all the tools of learning analytics at its disposal. The other stories show us why it is important to go beyond these tools if VET analytics is to effectively optimise the entire VET system.

Second takeaway: The data is an essential part of the technology, not a side effect. The second takeaway is '*Pay attention to the data!*' We are aiming this mainly at the designers of learning technologies. The stories in this chapter show that ignoring produced data fails to tap in the potential of learning technologies. In the case of the TinkerLamp, hiding the interaction data from users was one of the main reasons why students were not learning. And in the case of Realto, only once Mina dug into the data did it become clear that the problem of in-company trainers and instructors failing to give feedback was more widespread and serious than we had realised.

Our takeaway from these stories is that the data being generated and logged by learning technologies is not a side effect but an essential part of the technology. Designers should recognise this and ensure that users can easily access and understand the data. Providing easy ways of accessing the data, filtering it and visualising will likely help ensure that the technology is being used effectively.

We applied this principle to the entire VET system in the Story of Emerging Skills. In that story, the users were the administrators and industrial organisations who decide on the VET curriculum every five years, and the data they were not using was job ad data containing information about skills in the labour market. Our research showed that this data contained information that could be used to predict emerging skills, but we have yet to provide the users with a way of using this information in their decision-making. If the other stories are any indication, once this data is brought into the decision-making process, it will help ensure that the 'technology' of the entire VET system works as intended.

Third takeaway: To improve the VET system, VET analytics must 'close the loop'. Our final takeaway is about what should be done with the results of VET analytics. Any results or insights should be used to 'close the loop'. In other words, they should be used as a source of feedback that can help the VET system improve itself. If the results of these analyses only end up in reports or papers, they will have minimal impact on the VET system. These insights need to be fed back into the system that generated the data so the system can keep itself on track.

In the TinkerLamp story, information extracted from the interaction data was visualised on the TinkerBoard dashboard. Instructors and students alike regularly consulted the dashboard to better understand what was happening in the classroom and instructors used it to connect the TinkerLamp activity to the concepts in the lesson. Without the TinkerBoard, it was more difficult for the instructors to identify students who had gone off track or for students to monitor their own activities in relation to their peers. The TinkerBoard provided a source of feedback: Only when it was introduced into the classroom did the TinkerLamp activity result in significant learning gains.

Closing the loop does not need to be a high-tech exercise. In the case of Realto, the information that instructors and in-company trainers were not providing enough feedback to students was used to close the loop in the form of a workshop. Christian showed teachers and in-company trainers how to see requests for feedback and how to respond to that feedback and explained the importance of providing feedback through the e-DAP system. Following the workshop, there was a notable increase in feedback given and a drop in the amount of time it took an in-company trainer or teacher to provide feedback. An analogous effect was present when manipulating the setting of the workshops (see Chapter 4).

We have yet to learn what will happen when we use the data on emerging skills to close the loop on the VET curriculum. We hope that it will help to make the VET system more agile, make the VET curriculum more relevant and help equip students with the skills and knowledge that will prepare them for the future of industry.

Appendix

Classrooms in Bulle		**Classrooms in Yverdon**	
No of Students	Condition	No of Students	Condition
15	No TinkerBoard	15	No TinkerBoard
17	TinkerBoard	16	TinkerBoard

Table 9-1 · The setup for the classroom study designed to evaluate the TinkerBoard

Sub-network type	**Apprentices count (%)**	**Teachers count (%)**	**Trainers count (%)**	**Binary reciprocity**
Apprentices	458 (80%)	NA	NA	0.44
Teachers to Apprentices	266 (47%)	54 (52%)	NA	0.21
In-company trainers to Apprentices	147 (26%)	NA	68 (86%)	0.49
Teachers to In-company trainers to Apprentices	53 (1%)	22 (21%)	15 (19%)	0.28

Table 9-2 · User distribution and reciprocity of Realto sub-networks

Chapter 10
Synthesis

Pierre Dillenbourg, Alberto Cattaneo, Jean-Luc Gurtner, Richard Lee Davis

As a general answer to our question, '*Which digital technologies contribute to enhancing (dual) vocational education?*', we proposed the Erfahrraum model, which can be described as a circular, iterative and incremental flow of learning activities, based on digitally captured experience, circulating across learning places (workplaces and school). Of course, a model always constitutes a simplification of reality: sometimes the VET system does not involve two spaces but a single one (e.g. when professional workshops are organised in schools) and, more often, three locations (i.e., the company, the school and the branch courses). Another simplification of our model is that professional experience is easier to capture in professions that produce artefacts (carpenters, florists, cooks) than when the core of the daily practices is a relationship with customers (salespersons, nurses, for example). On the one hand, those simplifications constitute the strength or even purpose of a model: they make the Erfahraum a tool to be manipulated as a 'tool to think with'. Some simplifications can indeed be viewed as particularly helpful given the complexity of the Swiss VET system.

On the other hand, simplifications have as a corollary that mapping the model to real situations is less straightforward. This is why we presented several learning technologies stories in various professions: chefs, bakers, beauticians, clothing designers, logisticians, carpenters, painters and gardeners. The learning technologies developed across these contexts are grounded in the same conceptual model but end up being very different precisely because implementing a conceptual model in a specific context is not a simple application process. It is a creative design process inspired by a conceptual framework. We conclude this book by highlighting four concepts that guide the design process of a VET learning environment.

- **To bridge.** Our main hypothesis in this endeavour has been that technologies can address the misalignment between the two legs of a dual system, the school and the workplace. By talking to teachers, apprentices and workplace supervisors, we quickly realised that there exists a 'skills gap' between these two places: what apprentices learn at school is not necessarily perceived by them as useful for their workplace activities and what they do in the workplace does not allow them to give meaning to what is taught at school. At the same time, we also realised that the articulation between the learning locations is a powerful opportunity for deep learning and professionals' development. With the Erfahrraum (see Chapters 2 and 3) we tried to develop a pedagogically valuable model to better articulate the rich experiences apprentices live in both learning contexts by means of digital tools. The Erfahrraum is the VET-specific tool teachers and instructors can use to design technology-enhanced learning activities to put this principle into action.
- **To network.** As mentioned several times, the Swiss VET system is not simply dual, it is far more complex. We detailed this complexity in Chapter 1, as well as the tensions this might generate between the different persons who interact with apprentices: teachers, branch courses instructors and in-company trainers. The Swiss VET system relies upon a complex network of professional, geographic and linguistic sub-networks. Since digital technologies are intrinsically communication technologies, one of their obvious affordances is to network VET stakeholders, that is, to support rich interactions and fluid information flows among all the individuals involved in the training of an apprentice. VET networks are different from the well-known social networks, first because members have very different roles and duties and, second, they are clustered into rather hermetic sub-networks (communities) with their own strong professional identities. Chapter 4 explored the needs and solutions for networking all actors involved in the VET training of a 'common' apprentice.
- **To manipulate.** One specific feature of VET schools as compared to general high schools is that many of the learning activities in these curricula share the need to manipulate physical objects or to perform professional gestures, which is more

rarely the case in general high schools. These VET curricula benefit from digital technologies in which apprentices have the opportunity to manipulate, physically or at least virtually realistic professional objects. When we started in 2006, the interactions between a learner and a learning environment were mostly limited to a mouse and a keyboard, at least in daily practice. To enrich learning with more physical interactions, we pioneered the development of tangible interfaces and AR systems (see Chapter 6 and 7). Nowadays, with the growth of the Internet of Things and the ubiquity of additive manufacturing, the continuity between digital and physical aspects does not need to be demonstrated anymore to the actors of the VET system.

- **To monitor.** The fourth hypothesis is a corollary of the second one. As we anticipated in the introduction, the more complex a system is, the more efforts need to be made to monitor the way it functions. Nowadays, not only machines like our cars or airplanes, but also social structures like the educational system, are equipped with inner and outer sensors that are used to regulate them. Technology can improve these regulation mechanisms, making them faster, and sustaining more informed, evidence-based decisions that can make them more adaptive and flexible systems that are closer to the world of work. Chapter 9 explained how the learning analytics developed for VET education are much broader than those developed for general education as they model processes that go way beyond the classroom, involving all stakeholders of the apprentices' paths but, even beyond the VET systems, the evolution of the labour market, such as the emergence of new skills needs in companies.

Down the road, the contribution of this book has not been to prove that there is a magic technological solution to address the needs of the VET systems. These 16 years of experiments in schools are paved with many success stories and as many failures. As stated in the introduction, technologies have no intrinsic effect. Their effects depend upon the quality of the learning activities that apprentices and their educators will have to do while interacting with technologies. We provided the latter with a pedagogical model to design rich learning activities, integrating technologies of several different types and in several different ways, and we recursively and iteratively tested many of these possibilities in a continuous interaction between researchers and practitioners. We produced research, technological tools and applications, lesson plans and sets of learning activities. We introduced a pedagogical model and disseminated it in formal and informal training activities. We put apprentices' experiences at its core and learnt that the Erfahrraum can work with different kinds of experiences, from authentic to simulated, from mine to others'. We realised that this situated approach is also well aligned with and complementary to the official model used for VET teacher education in Switzerland (see Cattaneo & Boldrini, 2022). Together with the model, we also produced evidence of its results, on apprentices, on teachers, on the digital transformation of schools, and on the VET system and its connectivity across actors and learning locations.

Although our model is working well already, it can, of course, be improved, and it leaves room for further investigation and many questions that are still open, ranging from those related to the sustainability of the tools we produced, to the scalability of our approach, to the generative interplay between research, practice and politics. But we can summarise all this wonderful richness with one simple slogan: ***Design matters***. We co-designed technologies; we co-designed learning activities with teachers; we realised that combining technologies is sometimes better than focusing on some of them. Through these interactions, we somehow also redesigned the relations among VET stakeholders. Thereby, we modestly contributed to shaping the culture of VET when trying to exploit the affordances of digital technologies. We sought to summarise and share this 16-year-long journey in this book. We hope it will inspire the rich variety of learning activities that can be devised considering the digital tools available today.

Epilogue

Throughout the Dual-T project, we have benefited enormously from the guidance of our Advisory Board. This Epilogue, written by them, is an adapted version of their final report about the project.

The significance of Dual-T

Friedrich Hesse, Etienne Wenger-Trayner, Jim Pellegrino, Mike Sharples, Ulrich Hoppe and P. Robert-Jan Simons

Some reflections from the Advisory Board

In this epilogue, the Dual-T Advisory Board has contributed some reflections on the significance of Dual-T as a long-standing project. We consider this legacy along two axes:

1. In terms of the research outputs that Dual-T has contributed to various disciplines and the Swiss VET system
2. In terms of what we can learn from Dual-T as a demonstration project of long-term, design-based research, driven by innovation as well as a commitment to transforming practice

1. The legacy of the 'Erfahrraum' model

To inform the design of learning technologies so as to bridge the gap between school-based and workplace learning, the Dual-T team developed the pedagogical model of the Erfahrraum introduced in Chapter 2. This model has underpinned research and development throughout the project and is probably the most important output of Dual-T. Its theoretical significance is to present experiential learning as a perspective from learning theory (Dewey, Vygotsky, Engeström, Kolb) in order to conceptualise the gaps between learning in the workplace and learning at school. Its importance as a framework derives from being anchored in a model of the dual VET system:

- Bringing into play the relevant conceptual and practical elements of the dual vocational system's challenge, including the players and the locations involved (apprentices, teachers at school and supervisors at work)
- Proposing a dynamic model of their place and roles in a dual learning cycle typical of the Swiss vocational education system

Building on this model of the dual system, the key contribution of the Erfahrraum model is to widen the educational perspective by including a 'digital space', mediating the school-workplace relationship. This digital space integrated into the model, thus, opens an important area for educational technology. As the Erfahrraum graphic makes clear, the 'digital space' constitutes a full pedagogical companion to the dual VET 'physical space' (see Figure 2-1 in Chapter 2). The diagram shows how this additional element has transformed the one-dimensional school-workplace relationship into a two-dimensional space, whose four quadrants form a cycle, and thus provide additional 'degrees of freedom' to the model. The Dual-T endeavour can be seen as the exploration of the new degrees of freedom produced by this additional dimension.

To give this model a pedagogical embodiment, the technology development and application efforts of Dual-T have focused on two aspects of the model:

- The role of representations in populating the digital space and enabling new learning and pedagogical practices
- The processes by which representations contribute to the dual learning cycle by virtue of their ability to move across the model and to be transformed in the process

The digital space: the role of representations

To activate the model as an instrument of change, Dual-T's primary target and starting point have been the introduction of new types of representations, both fully and partially digital. These were conceived and created as carriers and initiators of transformations. In the Erfahrraum model, instances of these representations are referred to as artefacts in the digital space (quadrants II and III). Following the inherent dynamics of the model, these artefacts serve as connectors between workplaces (I) and schools (IV).
The pedagogical functions of the representations created in the context of Dual-T range from capturing, to sharing, to augmenting or even to expanding experience:

- **Capturing and sharing:** In their most basic role, digital representations are used to capture and possibly exchange information in a structured form. This would be the case of a 'learning diary'. Here, the computational representation is not meant to add domain-specific insights but to create and encapsulate content in a transportable way.
- **Annotating:** Combining captured pieces of information (images, sketches) with annotations, as exemplified in the area of fashion design, introduces domain-specific elements. These overlay the raw representation with annotations that capture professional practice and serve as visual languages.
- **Talking back:** Some representations are used to create a view of the world that provides feedback on actions. In the logistics domain, the warehouse simulation serves as a dynamic and observable model, replacing the real-world professional environment and facilitating rapid observation and experimentation. Similarly, the gardener programme provides feedback on a design across seasons. These representations have the characteristic of 'talking back' to the learner (Fischer, 2001).
- **Augmenting:** A further step is the provision of representations that provide understanding and insight into the domain. This is the case for the StaticAR application, which serves carpenter training by augmenting physical models of roof structures with theory-based explanatory visual representations of the interacting forces. Note that such representations can also provide feedback, for instance, about the likelihood of a designed structure collapsing.
- **Expanding:** Some representations expand the learning space for new exploration along various dimensions. The BloomGraph application for florists expands the space of possible arrangements that can be used for exploration and selection. The Mixplorer gardening application expands the time horizon of design by allowing the exploration of growth over time and across seasons.

The promise of these representations suggests important questions that have not yet been fully addressed in Dual-T. Exploring them would contribute to the further development of practice-based learning theory. For example:

- Conceiving profession-specific annotations as visual languages could be further explored theoretically and combined with ideas from 'domain-specific language' (DSL) design to strengthen the computational approach. The inclusion of DSL design principles could lead to standardising the use of domain-specific -plugins in the learning platform (be it Realto or a successor).
- An important concept in the Erfahrraum model is that of reflection on experience to promote learning. What is meant by reflection, however, remains under-theorised, and is mostly realised through the process of annotation and comments in learning journals. Articulating a coherent theory of reflection in the Erfahrraum model would give more rigour to key processes, such as selecting artefacts for capture, sharing them for collective thinking, and shaping reflective acts that promote learning. This includes deciding what is relevant and who is in the best position to make the decision.

As things stand, however, Dual-T has undoubtedly created a rich inventory of digital representations with convincing applications to VET needs in various contexts. This is and should be a source of inspiration for future research on technologies, VET and education more generally.

The digital space: the dynamic of the dual learning cycle

The Erfahrraum model is not only a set of representations and operations on them but a dynamic process across the dual cycle, as suggested by the arrow in the diagram. This led to the key theoretical notion of flow: representations are to be included in a dynamic journey across the model, transformed in the process by apprentices and others. This was given a technological embodiment in the Realto application. The Realto platform embodies the concept of flow by taking up the idea of a learning diary and combining it with general functions for capturing, annotating and sharing representations.

The main purpose of Realto's learning flows is to deepen the experience of apprentices by carrying a representation across contexts, with the idea, eventually, to take full advantage of the entire dual cycle of the Erfahrraum: to collect experiences, select relevant ones, share them to make them mutually available, contrast them with one's own or other's experiences, and annotate them for oneself or others (including apprentices, teachers and work supervisors). Realto, thus, creates a digital representational space to manage experiences in various ways and to design pedagogical activities that leverage the learning affordances of the process.

Important questions remain:

- At this point, not all representations contribute to the flow of the Erfahrraum model. For instance, it is not quite clear how representations expanding experiences such as those exploring floral arrangements and garden design fit in the experience cycle and how they can create and participate in meaningful flows.
- What the garden project is starting to explore is learning as a collective process by combining garden designs created by different students. It remains to be seen to what extent Realto-type flows can deliver on the promise of collective learning and to what extent this needs to be guided through activities designed by instructors. Exploring affordances for collective learning is an important avenue for future research.
- At a practical level, it is still unclear the extent to which the flows of digital representations can meaningfully transport them between the workplace and the school as institutions. Even when representations have been successfully used on one side, it remains to be shown that they can become a viable approach for creating strong pedagogical bridges between learning venues. Perhaps, a more modest but still exciting expectation would be that representations are used by the apprentices in their individual sense-making and interactions with others, so that the 'bridging over' remains a personal or collective mechanism, and not necessarily an exchange at the institutional level.

The Erfahrraum model and its various technology incarnations were an important research infrastructure for Dual-T. To have come to a point where we can realistically work on the questions and challenges raised here regarding representations and flows is itself a significant achievement. This is true for the context of VET and other contexts. We would, therefore, hope to see this agenda further pursued, both in VET research and in the learning sciences more generally.

2. Challenges and promises of innovation-driven, practice-oriented research

The lessons to be learned from the Dual-T project must be understood in the context of its enduring commitment: long-term research radically engaged with technological and pedagogical innovation in the real world.

A continuing issue for Dual-T has been how to demonstrate success. Situating the project within its methodology helps to make the case. From its first phase onwards, the project has applied a research methodology of Design-Based Research (DBR). First proposed in the early 1990s, DBR has now been widely adopted by researchers in the learning sciences and educational technology (Wang & Hannafin, 2005). It is a systematic but flexible methodology for improving educational theory and practice through a series of educational interventions that are designed, developed and implemented collaboratively by researchers and practitioners in real world settings (Towne & Shavelson, 2002). In this context, the work of Dual-T can be recognised as an excellent example of 'use-inspired strategic research' (Stokes, 1997). Such research focuses on theory development and testing while simultaneously seeking to address practical issues related to pedagogy and technology, such as the improvement of apprentice learning in areas of vocational education.

To evaluate the legacy of Dual-T as a demonstration project, it is important to emphasise the challenges of this double orientation to both innovation and practice.

- An innovation-driven, DBR project must straddle the tension between rigour and relevance. The ideal is to have high external validity in terms of direct contact, having concerns about educational and vocational practice while also demonstrating high internal validity with respect to matters of control, causality and generalisability (Cook & Campbell, 1979).
- The design orientation implies getting involved with practice and prototypically changing existing practices, usually starting with small-scale interventions. While many of Dual-T's formal studies have shown some promising effects, the samples were, by necessity, small.
- In pursuing innovation-driven interventions, Dual-T researchers did not remain in their labs to design prototypes evaluated under controlled situations. They went into the field: to the classroom, to the workplace, to professional association training locations. They worked with teachers, employers and apprentices. In attempting to bridge the gap between school and work with innovative projects, Dual-T met the political and institutional reality of the separation between the two contexts. They had to face questions such as: Who are the players? What are their goals? What accountability structures do they live under? How could they become interested in experimenting with innovation? It is, therefore, worth highlighting that the world of institutionalised practice is a hard place for innovation-driven researchers. The need to establish partnerships with practitioners requires enormous amounts of work that mostly remains invisible in accepted reporting formats. Under these circumstances, both the pursuit of research and its effects on the world are dependent on factors that the researchers do not fully control.

The Dual-T approach: multiple probes

Given the complexity of these challenges, progress comes not through a single research method moving in a linear trajectory, but from the combination of many probes. This approach gives rise to the double problem of creating a coherent narrative across the diversity of projects and assessing progress on multiple fronts – with multiple evaluation criteria and methods for measuring success. We see Dual-T's collection of probes as having addressed the following dimensions:

The crafting of a coherent narrative:

- Have a theoretical model for building pedagogical bridges across the school and the workplace
- Integrating technology innovation with the development of this model

The design of innovative technological artefacts that can serve learning in new ways:

- Novel educational technologies (e.g. the Tinkerlamp for logisticians, the Mixplorer software for social design of gardens, or the detection of emerging skills)
- Iterative design experiments with a series of prototypes refined through use (e.g. successive Tinkerlamp prototypes tested with apprentice logisticians)

The creation and evaluation of learning designs to leverage the development of new artefacts:

- Experimentation with pedagogical innovations related to new technologies (e.g. activity templates for Realto)

- Detailed assessment of learning processes and outcomes (e.g. eye-gaze studies of picture annotations)

The conduct of demonstration projects in real world settings:

- Adoption of new approaches in specific demonstration contexts (e.g. classroom orchestration techniques for leveraging the Tinkerlamp, learning journals for pastry chefs or simulations for office clerks)
- Enhancements to performance (e.g. chefs using videos taken in the workplace as classroom training aids to improve their practice or gardeners using AR for design and potentially for engaging customers)

The adoption of innovation at scale:

- The scaling-up of interventions through deployment of innovative technologies and practice (e.g. the adoption of Dual-T platforms with apprentices across multiple vocations)
- Partnerships that permit the adoption of innovation at scale (e.g. working with professional associations to digitise learning journals)

The complexity of these diverse, inter-related probes reflects the ambition of an innovation-driven, DBR project such as Dual-T. It is, therefore, worth considering each of these dimensions to reflect on what has been achieved and what can be learned from this work.

Crafting a coherent narrative: co-evolution of technology and pedagogy

Providing an overall framework for Dual-T is a key step, which we strongly encouraged from the early days. Here the evaluation question is:

- Can a pedagogical model anchor a wide diversity of projects in a shared theoretical discipline that helps make sense of their contribution to the overarching goal?

The development of the Erfahrraum is representative of this attempt. A distinctive aspect of Dual-T's approach is that the Erfahrraum model and the educational technologies have evolved in tandem through a series of interlinked projects. This has not been a single sequence of design experiments. Rather, the projects have reinforced each other, progressed the Erfahrraum model, informed the design of the platforms and addressed the overarching research question through a process of co-evolution.

For example, the original Erfahrraum model in 2012 had three phases: collection (of workplace artefacts), exploitation (of the artefacts as resources for learning), validation (of the expanded knowledge as professional activity). By 2022, as a result of instantiating the model in technology platforms and testing it in practice, the model has become richer and more complex, with multiple phases (executing, pre-selecting, capturing, post-selecting, augmenting, clustering, practicing/simulating) and additional levels and roles.

Similarly, the technology has evolved in power and complexity, from the original LearnDoc tools for bakers and chefs to the integrated Realto 1, 2 and 3 platforms. These technology developments have been informed by the Erfahrraum model, lab-based experiments, and workplace and classroom studies.

- At the micro-level, enhancements have been made for Realto to support the expanded Erfahrraum model (for example, in annotating images).
- At the meso-level, each iteration of Realto has to support software upgrades to cope with an expanded scale of deployment while retaining alignment with Erfahrraum.
- At the macro level, recent experience has shown that Erfahrraum can be enacted (to some extent) without Realto, using commercial technology such as Microsoft Teams.

Over the course of Dual-T, it was possible to ask of each project where it fits in the Erfahrraum model and what it contributes to it (a nagging question we kept asking). Admittedly not all projects cleanly fit in this model/technology interplay. For instance, we have noted that the expansion of search spaces or the automated discovery of emerging skills can be difficult to place in the Erfahrraum in its current state. But it is the nature of the innovation-driven co-evolution of technology and pedagogical model that one has to start some projects that are beyond the current model – with the potential of pushing it on.

Still, the discipline of co-evolution of theory and practice has been a hallmark of Dual-T. It has produced a model and a foundation for new research that should remain a core element of new programmes. It will make it easier for further VET research to be grounded in a theoretical foundation. Indeed, we believe that the aims of Dual-T – to use technology innovation to improve the connection between workplace learning and school-based learning – cannot succeed without Erfahrraum and its further instantiations. Future work should recognise this achievement and consider how new versions of the Erfahrraum model can be embedded in VET education and practice.

Technological innovation

Dual-T has produced a large number and variety of innovative artefacts over the years. The evaluation question is:

- Do the new artefacts do something useful or promising that could not be done before?
- Do they open new avenues for experimentation?

In this regard, we believe that Dual-T has been unusually successful. Even if we sometimes felt that it was shooting in all sorts of directions, we know that a proliferation of probes is the wellspring of inventiveness. The demos were always an inspiring part of our meetings, and we heard many reports of VET teachers responding with excitement. Admittedly this is a subjective evaluation, but technological innovation is as much an art as a science. And it is not insignificant that a group of seasoned teachers and veteran educationalists like us have found the technology exciting, just as the film academy awards are not rendered insignificant from involving the subjective evaluation of industry leaders. As we mentioned, the mere scope and diversity of the inventory of innovation should inspire the educational technology community to engage in research and development.

Innovation-driven interventions in practice with detailed evaluations

To see whether technical innovation lives up to its promise requires the design of activities to explore its effect in use. Here the evaluation question is:

- Does the use of a new artefact in well-designed activities make a significant difference to learning processes and outcomes?

Along this dimension, Dual-T has endeavoured to design formal assessments of pedagogical effects of innovations through well controlled experimental and quasi-experimental designs, with random assignment of individuals to treatments. From the published studies of project outcomes, there is preliminary empirical support for usability and impact on a range of learning outcomes, including understanding, observational skills, development of metacognitive strategies and acquisition of declarative knowledge with respect to reflective skills development. The evidence in the empirical studies remains preliminary given the small number of cases used for evaluation.

Also significant, however, were the qualitative reactions and testimonies of users (mostly teachers and apprentices, not much from employers) that were collected in some cases (e.g. logistician apprentices and gardener instructors). Again, the responses were promising, but the numbers were relatively small and a more systematic collection and analysis of testimonies from participants will be required to make broader claims of scalability.

Adoption in demonstration projects: the need for collaboration

The deployment of new artefacts in real world settings requires the development of new practices. In schools, this includes new practices in activity design, instruction and classroom orchestration. In the workplace, new activities need to be developed to capture moments of practice and provide feedback. (This includes complying with local demands, such as the fear expressed by some employers that competitive secrets will leak out.) Here, the evaluation question is:

- How relevant and useful have specific demonstration projects been to their contexts?
- What level of generality do these demonstration projects indicate in the aggregate?

A few demonstration projects have included enough apprentices to show reliably significant effects, for instance, in the case of office clerks. Even if the numbers have mostly remained small, there is preliminary evidence that the use of presentations across the dual cycle affects the giving of workplace feedback: when based on evidence and more specifically related to particular situations, feedback tends to become less corrective and prescriptive and more supportive. Presentations and annotations may also change the communication style, enabling it to become more student-driven and dialogical rather than assertive and tutor-driven. Such communication of feedback is better accepted and integrated by the apprentices who then can progress from hetero-assessment to self-assessment.

Over the years, demonstration projects have occurred in enough contexts to indicate feasibility. Convincing evidence of the generality of the approach comes from its introduction across a significant range of professions, from bakers and chefs to carpenters and painters, to gardeners and florists, to clothes designers and office clerks. While the level of use in practice has been variable, the perceived relevance has been widespread. Finding willing practitioners to join as partners in developing new practices is always a challenge for demonstration projects, but the teachers who have participated in Dual-T as partners have usually been very positive.

Adoption at scale in institutionalised practice

The Dual-T team worked very hard to encourage its adoption in the Swiss dual VET education system. Here the evaluation question is:

- What is the extent of the adoption of research-based innovations in practice for specific professions or across the system?

This has been a much more difficult task. Dual-T has achieved a modest scale of impact on VET education in Switzerland. Realto has only some 1,500 users across multiple professions but there is now interest from a healthcare training centre adopting the Erfahrraum model to inform its pedagogy; the LearnDoc and the e-Dap platforms have seen some sustained use throughout the project, and X schools are now equipped with the Tinkerlamp, but there is no clear strategy to sustain the technology or the pedagogy beyond the end of the project.

That such adoption has been limited is not for lack of trying. The Dual-T team talked to representatives of many schools and professional associations. They even created a full-time position to help with the adoption of Realto. The project's limited impact has been a disappointment for both the researchers and for us as advisers. To some extent, this is a limitation of DBR, which is a methodology for design interventions, not systemic change. Few research projects in educational technology have achieved enduring scale and sustainability, and most of these have required decades of continuous research and the backing of wealthy institutions and companies.

One of the insights of this learning journey has been to fully recognise how much adoption at scale is beyond the purview of what researchers can do – or even influence – on their own. That so much lies beyond their control may require earlier commitments from professionals and federal agencies to the project and its aspirations. Such commitments beyond research funding may increase the likelihood of incorporating innovations in day-to-day practice – but with the risk that conservative tendencies in existing structures may hamper the prolific production and testing of radical innovations.

Systemic effects: a culture of innovation

There is a broader effect to consider when assessing the legacy of Dual-T. When researchers engage in innovation-driven, practice-oriented research over a long time, as the Dual-T ones did, they interact with different parts of the system, build new networks, create new conversations and expose people to new thinking. At our meetings, we heard consistent formal and informal reports of the connections and discussions with key VET players, such as teachers, school leaders, teacher trainers and professionals. Some leaders of Dual-T were invited to give presentations to professional associations. Over time, such a process influences people, even if some have reasons to resist a specific innovation. In other words, these interactions keep expanding the horizon of the possible – the first step in creativity and cultural change. Here the evaluation question is:

- In a traditional system such as the dual VET, what is the effect of persistent and relentless injection of inventiveness?
- How does this affect the long-term ability of such a complex system to evolve, adapt and learn?

When we consider the evolution of Dual-T and its legacy, it is important to include considerations along these lines. Such a diffuse effect is admittedly very difficult to assess with certainty, and we do not have a definite answer. But from hearing consistent reports from Dual-T leaders, we strongly suspect that it is an emergent outcome. The case of Dual-T has demonstrated that this sustained injection of inventiveness can be done by researchers who are steeped in traditions of both creativity and rigour and are external to the system – provided they have the patience and support to engage with the system over a long time. This cultural effect may well, in the last analysis, matter more for the future of Swiss VET than the current level of adoption of specific ideas or technologies.

What now?

Any systemic transformation requires playing the long game and we commend the Swiss federal government for supporting this project for so many years. Such enduring commitment is extremely rare for research projects in the social sciences. But if we are right about Dual-T's pioneering efforts at pedagogical, cultural and institutional transformation, it will be important to find some ways to press on. We conclude with a few thoughts about the future.

The Realto platform

A practical, theory-based technology such as the Realto platform has proved useful in various professions as well as in research. However, its longevity is a concern given the need for ongoing maintenance and support by Swiss federal and/or corporate entities. We applaud the efforts to find a partner to take it on, but schools and professional associations are understandably hesitant to adopt it for use in VET without clear long-term prospects. We had long been concerned about the difficulties of sustaining a research-based prototype and taking it into the world of institutionalised practice at scale. Perhaps we should have been even more insistent about this challenge and Dual-T may have looked at alternative avenues earlier. That said, Dual-T is now creating a series of scenarios for inspiring educators to adopt the approach of the Erfahrraum/Realto model, using widely available and supported technology platforms. We think that this is an excellent development for a more enduring legacy.

The Erfahrraum model

As a conceptual model of the links between the workplace and the school, Erfahrraum has proved essential in guiding a diverse programme of research focused on VET practice. As a research heuristic and a pedagogical framework, it models key aspects of the Swiss VET system with a clear place for digital technologies. It has the potential to be a kind of base for guiding current and future explorations of research and development, technology-based or otherwise, related to the improvement of dual education where, as in Switzerland, learning and instruction are supposed to take place both at school and in the workplace. As such, the Erfahrraum model is a big step forward.

The value of the model is real despite the recognition that Dual-T's current body of work cannot yet be said to 'instantiate' or 'validate' all the assumptions and dimensions of the model. Some questions remain regarding the theoretical nature of the model. Following the definitions of Becker (2015), is it a learning theory (about how people learn), an instructional theory (how people should teach), or an instructional design model (a recipe for creating instructional interventions)? It is none of these, but it contains elements of each. It would be worth reflecting on whether some version of it needs to be more prescriptive to become useful for designers of VET programmes. All this is a matter of further work.

VET teacher training

One of the most promising avenues for leveraging and pursuing the legacy of Dual-T is in the context of VET education and professional research. Training the next generations of VET teachers should include studying the Erfahrraum model and examples of the innovative use of technology of the type proposed by Dual-T. This would give future teachers a broader view of what they are doing and open their imaginations to new possibilities. Exposing practitioners and managers to innovation and experimentation would create openings for the continued injecting of innovativeness into the Swiss VET culture.

Book as a dissemination strategy

Finally, concluding the project with the publication of a book is an appropriate way to disseminate its legacy beyond publications in journals. Indeed, Dual-T's contributions and legacy are best understood as a whole package rather than separate pieces. A book can show the scope of inventiveness that is possible while offering a theoretical framework to make sense of it. It can serve as a source of inspiration, not only for VET programme designers, but also for researchers, teachers, policymakers and other players who want to improve VET learning.

In closing

It has been our honour and pleasure to be involved in Dual-T. We were able to bear witness – and sometimes contribute – to the work of researchers driven by a commitment to using their talents, skills and privileged positions to make a real difference in practice. This has been a core tenet of the whole project and one reason we were happy to continue to serve on the advisory board for so long. We are grateful for the opportunity that was presented.

References

Akkerman, S. F., & Bakker, A. (2011). Boundary crossing and boundary objects. *Review of educational research, 81*(2), 132-169.

Alavi, H. S., Dillenbourg, P., & Kaplan, F. (2009). Distributed awareness for class orchestration. In *European Conference on Technology Enhanced Learning* (211-225). Springer, Berlin, Heidelberg.

Aprea, C., Sappa, V., & Tenberg, R. (2020). Connectivity and integrative competence development in vocational and professional education and training (VET/PET): an introduction to the special issue. *Zeitschrift für Berufs-und Wirtschaftspädagogik: ZBW. Beiheft, 2020*(29), 13-16.

Baker, R. S. J. D. (2010). Data mining for education. *International encyclopedia of education, 7*(3), 112-118.

Bakker, A., & Akkerman, S. (2019). The learning potential of boundary crossing in the vocational curriculum. In D. Guile, & L. Unwin (Eds.), *The Wiley handbook of vocational education and training*, 349-372.

Balacheff, N. (1994). La transposition informatique. Note sur un nouveau problème pour la didactique. *Vingt ans de didactique des mathématiques en France*, 2, 132-138.

Basile, O. (2020). Gonna a teli e le sue varianti: ricerca e sviluppo. *Lavoro di certificazione CAS Formatore/Formatrice digitale*. Lugano: SFUVET.

Boldrini, E., & Cattaneo, A. (2014). Scaffolding collaborative reflective writing in a VET curriculum. *Vocations and learning, 7*(2), 145-165.

Bonnard, Q., Verma, H., Kaplan, F., & Dillenbourg, P. (2012a). Paper interfaces for learning geometry. In *European Conference on Technology Enhanced Learning* (pp. 37-50). Springer, Berlin, Heidelberg.

Bonnard, Q., Jermann, P., Legge, A., Kaplan, F., & Dillenbourg, P. (2012b). Tangible paper interfaces: interpreting pupils' manipulations. In *Proceedings of the 2012 ACM International Conference on Interactive Tabletops and Surfaces* (pp. 133-142).

Boroujeni, M. S. (2018). *Discovering Interaction Patterns in Online Learning Environments* (No. 8238). *Unpublished PhD Thesis* EPFL.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn* (Vol. 11). Washington, DC: National academy press.

Breslin, F. C., Polzer, J., MacEachen, E., Morrongiello, B., & Shannon, H. (2007). Workplace injury or "part of the job"?: Towards a gendered understanding of injuries and complaints among young workers. *Social Science & Medicine, 64*(4), 782-793.

Bronckart, J. P., & Plazaola Giger, M. I. (1998). La transposition didactique. Histoire et perspectives d'une problématique fondatrice. *Pratiques, (97-98)*, 35-58.

Caruso, V., Cattaneo, A., & Gurtner, J. L. (2017). Creating technology-enhanced scenarios to promote observation skills of fashion-design students. *Form@ re-Open Journal per la formazione in rete, 17*(1), 4-17.

Caruso, V., Cattaneo, A., & Gurtner, J-L. (2020). Exploring the potential of learning documentation as a boundary object in the Swiss vocational education and training system. In: C. Aprea, V. Sappa, & R. Tenberg (Eds.), *Connectivity and integrative competence development in vocational and professional education and training (VET/PET)* (pp. 213–231). Stuttgart: Franz Steiner Verlag.

Cattaneo, A., & Boldrini, E. (2016). Individual and collaborative writing-to-learn activities in vocational education: An overview of different instructional strategies. In G., Ortoleva, M., Bétrancourt, M., S., Billett, S. (Eds), *Writing for professional development*, 188-208.

Cattaneo, A., & Boldrini, E. (2017). Learning from errors in dual vocational education: Video-enhanced instructional strategies. *Journal of Workplace Learning, 29*(5), 357-373.

Cattaneo, A., & Boldrini, E. (2022). Erfahrraum und Situationsdidaktik. Analogien, Unterschiede und Herausforderungen. In G. Ghisla, E. Boldrini, C. Gremion, F. Merlini, & E. Wüthrich (Eds.), *Didaktik und Situationen. Ansätze und Erfahrungen für die Berufsbildung* (pp. 119-130). Bern: hep.

Cattaneo, A., Felder, J. & Gurtner, J-L. (2021). Digital tools as boundary objects to support connectivity in dual vocational education. In E. Kyndt, S. Beausaert and I. Zitter (Eds.), *Developing connectivity between education and Work. Principles and Practices* (pp. 137-157). New York: Routledge.

Cattaneo, A., & Motta, E. (2021). "I Reflect, Therefore I Am… a Good Professional". On the Relationship between Reflection-on-Action, Reflection-in-Action and Professional Performance in Vocational Education. *Vocations and Learning, 14*(2), 185-204.

Cattaneo, A., Motta, E., & Gurtner, J. L. (2015). Evaluating a mobile and online system for apprentices' learning documentation in vocational education: Usability, effectiveness and satisfaction. *International Journal of Mobile and Blended Learning (IJMBL), 7*(3), 40-58.

Cattaneo, A., van der Meij, H., Aprea, C., Sauli, F., & Zahn, C. (2018). Designing instructional activities integrating hypervideo: An operative model. *Interactive learning environments, 27*(4), 508-529.

Cattaneo, A., Boldrini, E., & Lubinu, F. (2020). "Take a look at this!". Video annotation as a means to foster evidence-based and reflective external and self-given feedback: A preliminary study in operation room technician training. *Nurse Education in Practice, 44*, 102770.

Cattani, P. (2020). *Lavoro di certificazione CAS Formatore/Formatrice digitale*. Lugano: SFUVET.

Chatti, M. A., Dyckhoff, A. L., Schroeder, U., & Thüs, H. (2012). A reference model for learning analytics. *International Journal of Technology Enhanced Learning, 4*(5-6), 318-331.

Clow, D. (2013). An overview of learning analytics. *Teaching in Higher Education, 18*(6), 683-695.

Cook, T. D., & Campbell, D. T. (1979). *Quasi-experimentation: Design and analysis issues for field settings*. Boston, MA: Houghton Mifflin Company.

Coppi, A. E., & Cattaneo, A. (2021). Fostering Apprentice Beauticians' Visual Expertise Through Annotations: A Design Experiment Using the Platform Realto. *RedFame, 9*(7), 27-40.

Coppi, A. E., Oertel, C., & Cattaneo, A. (2021). Effects of Experts' Annotations on Fashion Designers Apprentices' Gaze Patterns and Verbalisations. *Vocations and Learning, 14*(3), 511-531.

Coppi, A. E. (2021). The Potential of Using Annotations to Foster Visual Expertise. *Unpublished PhD Thesis*. University of Fribourg.

De Jong, T., & Van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of educational research, 68*(2), 179-201.

Dillenbourg, P., & Jermann, P. (2010). Technology for classroom orchestration. In M. S. Khine & I. M. Saleh (Eds.), New Science of Learning, (pp. 525-552). Springer, New York, NY.

Dillenbourg, P., Zufferey, G., Alavi, H., Jermann, P., DoLenh, S., Bonnard, Q., Cuendet, S. and Kaplan, F. (2011) Classroom orchestration: The third circle of usability. *Proceedings of the 9th Computer-Supported Collaborative Learning Conference*, Hong Kong. July 4-8, 2011.

Do-Lenh, S., Jermann, P., Cuendet, S., Zufferey, G., & Dillenbourg, P. (2010). Task performance vs. learning outcomes: a study of a tangible user interface in the classroom. In *European Conference on Technology Enhanced Learning* (pp. 78-92). Springer, Berlin, Heidelberg.

Do-Lenh, S., Jermann, P., Legge, A., Zufferey, G., & Dillenbourg, P. (2012). TinkerLamp 2.0: designing and evaluating orchestration technologies for the classroom. In *European Conference on Technology Enhanced Learning* (pp. 65-78). Springer, Berlin, Heidelberg.

Evi-Colombo, A., Cattaneo, A., & Bétrancourt, M. (2020). Technical and pedagogical affordances of video annotation: A literature review. *Journal of Educational Multimedia and Hypermedia, 29*(3), 193-226.

Faucon, L., Olsen, J. K., Haklev, S., & Dillenbourg, P. (2020). Real-Time Prediction of Students' Activity Progress and Completion Rates. *Journal of Learning Analytics, 7*(2), 18-44.

Fischer, G. (2001). Articulating the task at hand and making information relevant to it. *Human–Computer Interaction, 16*(2-4), 243-256.

Furlan, N. (2017). Feedback im Kontext von Lehrbetrieben. *Unpublished PhD Thesis*, University of Fribourg. *http://doc.rero.ch/record/305058*.

Gianetti, C. (2021). Cuochi AFC, apprendere con le nuove tecnologie e nuovo ruolo del docente. Lugano: SFUVET.

Georgiou, Y. & Kyza, E. (2018) Relations between student motivation, immersion and learning outcomes in location-based augmented reality settings, *Computers in Human Behavior, 89*, pp. 173-181.

Goodwin, C. (2015). Professional vision. In S. Reh, K. Berdelmann, & J. Dinkelaker (Eds.), *Aufmerksamkeit* (pp. 387-425). Springer VS, Wiesbaden.

Griffiths, T., & Guile, D. (2003). A connective model of learning: The implications for work process knowledge. *European educational research journal, 2*(1), 56-73.

Guile, D., & Griffiths, T. (2001). Learning through work experience. *Journal of education and work, 14*(1), 113-131.

Guile, D; (2020) Rethinking connectivity as recontextualisation: issues for research and practice. In C. Aprea, V. Sappa & R. Tenberg (Eds.), *Konnektivität und lernortintegrierte Kompetenzentwicklung in der beruflichen Bildung* (pp. 35-54). Franz Steiner Verlag Wiesbaden GmbH: Stuttgart, Germany.

Hämäläinen, R., & Cattaneo, A. (2015). New TEL environments for vocational education–teacher's instructional perspective. *Vocations and learning, 8*(2), 135-157.

Illeris, K. (2011). *The Fundamentals of Workplace Learning. Understanding How People Learn in Working Life*. New York: Routledge.

Kapur, M. (2008). Productive failure. *Cognition and Instruction, 26*(3), 379-424.

Kim, K. G., Oertel, C., & Dillenbourg, P. (2021). How florist apprentices explore bouquet designs: Supporting design space exploration for vocational students. *International Journal for Research in Vocational Education and Training, 8*(1), 65-86.

Kim, K. G., Oertel, C., Dobricki, M., Olsen, J. K., Coppi, A. E., Cattaneo, A., & Dillenbourg, P. (2020). Using immersive virtual reality to support designing skills in vocational education. *British Journal of Educational Technology, 51*(6), 2199-2213.

Kim, K. G., Davis, R. L., Coppi, A., Cattaneo, A., & Dillenbourg, P. (2022). Mixplorer: Scaffolding Design Space Exploration through Genetic Recombination of Multiple Peoples' Designs to Support Novices' Creativity. *In Conference on Human Factors in Computing Systems (CHI'22)*.

Kyndt, E., Beausaert, S., & Zitter, I. (2021). *Developing Connectivity Between Education and Work: Principles and Practices*. London: Routledge.

Lave, J., & Wenger, E. (2001). Legitimate peripheral participation in communities of practice. In J. Clarke, A. Hanson, R. Harrison, & F. Reeve (Eds.), *Supporting lifelong learning* (pp. 121-136). London: Routledge.

Lucchi, A., Jermann, P., Zufferey, G., & Dillenbourg, P. (2010, January). An empirical evaluation of touch and tangible interfaces for tabletop displays. In *Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction*, (pp. 177-184).

Lucignano, L., Cuendet, S., Schwendimann, B., Shirvani Boroujeni, M., Dehler, J. et al. (2014) My Hands or my Mouse: Comparing a Tangible and Graphical User Interface using Eye-Tracking Data. Fablearn, 2014, Stanford, CA USA, October 25-26, 2014.

Martín-Gutiérrez, J., Navarro, R. E., & González, M. A. (2011, October). Mixed reality for development of spatial skills of first-year engineering students. *Frontiers in Education Conference (FIE)*. IEEE.

Mauroux, L., Dehler Zufferey, J., Jimenez, F., Wehren, R., & Gurtner, J. L. (2013). Autorégulation des apprentissages et dossiers de formation en formation professionnelle. *L'apprentissage autorégulé: Perspectives théoriques et recherches empiriques*, 195-227.

Mauroux, L., Könings, K. D., Zufferey, J. D., & Gurtner, J. L. (2014). Mobile and online learning journal: Effects on apprentices' reflection in vocational education and training. *Vocations and Learning, 7*(2), 215-239.

Mauroux, L., Zufferey, J. D., Rodondi, E., Cattaneo, A., Motta, E., & Gurtner, J. L. (2016). Writing reflective learning journals: Promoting the use of learning strategies and supporting the development of professional skills. In G., Ortoleva, M., Bétrancourt, M., S., Billett, S. (Eds), *Writing for professional development* (pp. 107-128). Brill.

Mayer, R. E. (2001). *Multimedia Learning*. Cambridge: Cambridge University Press.

Mayer, R. E. (Ed.) (2014). *The Cambridge handbook of multimedia learning* (2nd ed.). New York: Cambridge University Press.

Meier, A., Spada, H., & Rummel, N. (2007). A rating scheme for assessing the quality of computer-supported collaboration processes. *International Journal of Computer-Supported Collaborative Learning, 2*(1), 63-86.

Motta, E., Boldrini, E., & Cattaneo, A. (2013). Technologies to "bridge the gap" among learning contexts in vocational training. In P. M. Pumilia-Gnarini, E. Favaron, E. Pacetti, J. Bishop, & L. Guerra (Eds.), *Handbook of research on didactic strategies and technologies for education: Incorporating advancements* (pp. 247-265). IGI Global.

Motta, E., Cattaneo, A., & Gurtner, J. L. (2014). Mobile devices to bridge the gap in VET: Ease of use and usefulness as indicators for their acceptance. *Journal of Education and Training Studies, 2*(1), 165-179.

Motta, E., Cattaneo, A., & Gurtner, J. L. (2017). Co-regulations of learning in small groups of chef apprentices: when do they appear and what influences them?. *Empirical Research in Vocational Education and Training, 9*(1), 1-20.

Müller, B., & Schweri, J. (2015). How specific is apprenticeship training? Evidence from inter-firm and occupational mobility after graduation. *Oxford Economic Papers, 67*(4), 1057-1077.

Nova, N., Girardin, F., & Dillenbourg, P. (2005, November). 'Location is not enough!': An empirical study of location-awareness in mobile collaboration. In *IEEE International Workshop on Wireless and Mobile Technologies in Education (WMTE'05)* (pp. 21-28). IEEE.

Peter, K. (2014). Der Einfluss von Online-Plattformen auf Lernortkooperation: Fallanalyse in zwei Kantonen anhand ausgewählter Berufe (Doctoral dissertation, University of Zurich). *www.zora.uzh.ch/id/eprint/164362/1/20142140.pdf*

Resnick, L. B., & Science National Research Council (US). Committee on Research in Mathematics. (1987). Education and learning to think.

Salzmann, C., Gillet, D., & Huguenin, P. (2000). Introduction to real-time control using Lab-VIEWTM with an application to distance learning. *International Journal of Engineering Education, 16*(5), 372-384.

Sappa, V., & Aprea, C. (2014). Conceptions of connectivity: How Swiss teachers, trainers and apprentices perceive vocational learning and teaching across different learning sites. *Vocations and Learning, 7*(3), 263-287.

Sauli, F., Cattaneo, A., & van der Meij, H. (2018). Hypervideo for educational purposes: a literature review on a multifaceted technological tool. *Technology, pedagogy and education, 27*(1), 115-134.

Schneider, B., Jermann, P., Zufferey, G., & Dillenbourg, P. (2010). Benefits of a tangible interface for collaborative learning and interaction. *IEEE Transactions on Learning Technologies, 4*(3), 222-232.

Schneider, B., Sharma, K., Cuendet, S., Zufferey, G., Dillenbourg, P., & Pea, R. (2018). Leveraging mobile eye-trackers to capture joint visual attention in co-located collaborative learning groups. *International Journal of Computer-Supported Collaborative Learning, 13*(3), 241-261.

Schön, D. A. (1987). *Educating the reflective practitioner: Toward a new design for teaching and learning in the professions.* Jossey-Bass.

Schwartz, D. L., & Bransford, J. D. (1998). A time for telling. *Cognition and Instruction, 16*(4), 475-5223.

Schweizerische Koordinationsstelle für Bildungsforschung (Ed.). (n.d.). *L'éducation en Suisse: Rapport 2018.* CSRE.

Schwendimann, B. A., Cattaneo, A. A., Dehler Zufferey, J., Gurtner, J. L., Bétrancourt, M., & Dillenbourg, P. (2015). The 'Erfahrraum': A pedagogical model for designing educational technologies in dual vocational systems. *Journal of Vocational Education & Training, 67*(3), 367-396.

Schwendimann, B. A., De Wever, B., Hämäläinen, R., & Cattaneo, A. A. (2018). The state-of-the-art of collaborative technologies for initial vocational education: A systematic literature review. *International Journal for Research in Vocational Education and Training (IJRVET), 5*(1), 19-41.

Seidel, T., & Stürmer, K. (2014). Modeling and measuring the structure of professional vision in preservice teachers. *American educational research journal, 51*(4), 739-771.

Sherin, M. G., & Russ, R. S. (2011). Accessing mathematics teachers' in-the-moment noticing. In M. G. Sherin, V. R. Jacobs, & R. A. Philipp (Eds.), Mathematics teacher noticing (pp. 109-124). Routledge.

Stokes, D.E. (1997). *Pasteur's Quadrant – Basic Science and Technological Innovation*. Washington, DC: Brookings Institution Press.

Strupler Leiser, M., & Wolter, S. (2013). Kann man mit dem öffentlichen Beschaffungswesen Lehrstellen fördern? (No. 0085). University of Zurich, Department of Business Administration (IBW).

Stürmer, K., Könings, K. D., & Seidel, T. (2013). Declarative knowledge and professional vision in teacher education: Effect of courses in teaching and learning. *British Journal of Educational Psychology, 83*(3), 467-483.

Taylor, A., & Freeman, S. (2011). 'Made in the trade': youth attitudes toward apprenticeship certification. *Journal of Vocational Education & Training, 63*(3), 345-362.

Towne, L., & Shavelson, R. J. (2002). *Scientific research in education.* National Academy Press Publications Sales Office.

Tynjälä, P., Heikkinen, H., & Kallio, E. (2021). Integrating work and learning in higher education and VET: Theoretical point of view. *The SAGE Handbook of Learning and Work,* 62.

van Es, E. A., Cashen, M., Barnhart, T., & Auger, A. (2017). Learning to notice mathematics instruction: Using video to develop preservice teachers' vision of ambitious pedagogy. *Cognition and Instruction, 35*(3), 165-187.

Wang, F., & Hannafin, M. J. (2005). Design-based research and technology-enhanced learning environments. *Educational Technology Research and Development, 53*(4), 5-23.

Wuttke, E., & Seifried, J. (2012). *Evaluation in der Lehrer/-innen-Bildung–Diskussionslinien und exemplarische Umsetzung.*

Yazdanian, R. (2021). Predicting labour market needs using machine learning. (No. Thesis: 8998). EPFL.

Yazdanian, R., Davis, R. L., Guo, X., Lim, F., Dillenbourg, P., & Kan, M. Y. (2022). On the radar: Predicting near-future surges in skills' hiring demand to provide early warning to educators. *Computers and Education: Artificial Intelligence, 3.*

Zuckerman, O., Arida, S., & Resnick, M. (2005, April). Extending tangible interfaces for education: digital Montessori-inspired manipulatives. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 859-868).

Zufferey, G. (2010). The complementarity of tangible and paper interfaces in tabletop environments for collaborative learning (doctoral dissertation), *https://infoscience.epfl.ch/record/149389?ln=fr*).

Zürich, B. K. (2018). Entwicklung der Berufsbildung im Kanton Zürich 2008–2017. (*www.zh.ch/content/dam/zhweb/bilder-dokumente/themen/bildung/bildungssystem/studien/entwicklung_der_berufsbildung_ 2008bis2017.pdf*)

This book summarises 15 years of research (2007-2021) on the exploitation of digital technologies for VET. In other words, our activities started the same year as the first iPhone was launched! Four research groups formed the leading house on the topic, named DUAL-T, where T stands for technologies and DUAL refers to the Swiss VET system, relying to a great extent upon the alternating of days at school and days in the workplace. This uniquely long-term research scheme has gathered more than 50 research scientists, produced 13 doctoral theses, led to the development of multiple digital learning environments and enabled dozens of empirical studies on thousands of apprentices and hundreds of teachers and company trainers. DUAL-T developed a network of stakeholders, including vocational schools and companies, but also many professional organizations and cantonal or national public entities. This book does not provide a detailed account of all these activities, which have been published elsewhere.
But it proposes several answers to the question:
"Which digital technologies contribute to the enhancement of vocational education?"