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education as loosely coupled system of technology and pedagogy

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The recent development of education seems to be driven mainly by technology; assigning version numbers is an attempt to tame this development. But education is more complex than buzzwords like “Learning 4.0” may suggest. In this article, we argue for viewing education as a loosely coupled system of two interacting layers, technology and pedagogy: closely connected, but not glued together. Using several examples, we show that sometimes technological innovations trigger pedagogical innovations and sometimes pedagogical needs initiate the development of technological solutions. We intend the model of loosely coupled layers of technology and pedagogy as a starting point for opening an overdue discussion on how to make the best use of technology for teaching and learning. We argue that complementing technology with established and proven principles of situated contextualized pedagogy is a key element for the future development of education.

Keywords: contextualization, loosely coupled system, pedagogy, technology

Introduction

Like many fields today, education seems to be driven by technology. There is a tendency to assign version numbers to technologically defined ages, industrial revolutions, and also to educational developments. It makes it easier to hide the complexity and make progress (whether made-up or real) visible. Yet these numbers remain arbitrary and depend on the argumentative goals of the one who counts.

In this article, we will favor a *longue durée* view of education as a system formed by the continuous interaction of technology and pedagogy. We show why version numbers do not solve any problems in education and educational technology. Instead, we argue for a conceptual model of education as a system composed by two loosely connected layers: technology and pedagogy in mutual interaction. We take challenges and transformations due to the Covid-19 pandemic as magnifying glass to highlight the two layers and their connection. We then use our model to argue that pedagogy and technology complement each other to create a sound concept of contextualized and personalized learning.

Tamed by Numbers?

Can educational technology be tamed by naming and versioning?

The last decades witnessed the emergence and disappearance of *computer-based training* (CBT), *web-based learning* and *web-based training* (WBT), later *new media in learning* and *e-learning*. Today we talk about *digital learning* and *E-learning 2.0*. The *digital transformation* of learning is supposed to lead to *Learning 4.0* or even *Education 5.0* (Diaz Lantada, 2020).

Such version numbers clearly serve marketing purposes: the hope is that the target audience associates them with those used in other fields—*Learning 4.0* clearly refers to *Industry 4.0*, while *E-Learning 2.0* obviously borrows from *Web 2.0*, but the connotations are rarely made explicit.

Versioning systems in software engineering explicitly specify major and minor improvements of a product, and when and how to roll out a new release. For education, it is impossible to define major and minor development steps; we cannot come up with a list of recent improvements justifying a jump from *Learning 3.11* to *Learning 4.0* rather than to *Learning 3.12*. We need a different view of the history of education's development and the drivers of that development.

Education as Loosely Coupled System

Technological progress in education is sometimes triggered by pedagogical demands, sometimes pedagogy includes available technology into education. Technological progress often happens by chance and then has massive side-effects in society. In turn, societal progress—caused by earlier technological inventions—leads to purposeful development of technology (Norman, 1993, pp. 7–8). Progress is thus driven by two forces. We can easily apply this view to technology and pedagogy as two forces driving the development of education.

We here understand *technology* in education as objects and machines used for teaching and learning. We then can identify periods introducing and favoring certain devices for educational purposes: books, blackboards, feedback machines, etc. It is possible to place the first use of a specific technology in education on a timeline and align it with other developments in society.

We here understand *pedagogy* as theory and practice of teaching and learning. We can then identify certain shifts or educational transformations, such as the often-quoted behaviorist, cognitivist, constructivist paradigms, the introduction of competency-based learning (Hall & Jones, 1976) in the 1970s, the shift from an instructor-based to a learner-centered model, etc.

If we want to take a *longue durée* perspective, we need to consider education as a system, which evolves, but which is delimited by certain fixed structures; as Braudel (1958, p. 731) remarked, "[c]ertaines structures, à vivre longtemps, deviennent des éléments stables d'une infinité de générations."[1] Within these structures, from a systemic point of view, technology and pedagogy can be said to constitute two layers, which are connected, but in a flexible way, forming a "loosely coupled system" (Weick, 1976). It seems to be possible and useful to specifically work on one of these layers, but rather sooner than later, this implies changes on the other layer as well. We therefore argue that in order to achieve meaningful progress in the system as a whole, one needs to explicitly address *both* layers. There is no mechanism that ensures that development on the other layer will automatically follow in the intended way.

In the following sections, we give some examples to show that there never was a strict separation of technology and pedagogy as influences on education. Sometimes pedagogy focused on integrating technological progress into teaching and learning, sometimes technology aimed at supporting pedagogical ideas. Neglecting one of the layers inevitably causes failure, though. Perspective and context determine on which layer we place the starting point of a development.

Technological Layer

One can distinguish technology explicitly developed for educational purposes and technology whose affordances prompted its use in educational settings beyond its original purpose.

There are fierce discussions about "technology first, pedagogy follows" (or vice versa) at conferences, on blogs (Kerr, 2020; Krommer, 2017, 2019; Muuß-Merholz, 2020; Schöneberg, 2019), and on social media which had already started before the pandemic, but which have now become more urgent. These discussions are reductionist and assume an automatism. They are often triggered by offering or asking for "cool tools for teaching."[2] There is a public discussion, and there is also a need to work out concepts and terms suitable for discussing teaching and learning in a digitally transformed world. Curated lists of "good tools for good teaching" emphasize tools and technical aspects like availability and accessibility, but they do not take the contexts of learning scenarios into account.[3]

The following examples show technology developed in response to pedagogical demands.

Technology by Demand

A recurring pedagogical topos is that immediate and consistent feedback supports learning. In the 1920s, Pressey built mechanical devices that let people answer multiple choice questions (for a critical overview see Petrina, 2004), which Skinner developed further to provide *automated, immediate, and regular reinforcement*, aimed at triggering learning by drill (Skinner, 1958). Already back then debates centered on the technology and the machines used rather than on the underlying pedagogical principles and goals (Fry, 1960; Pressey, 1963).

The automation of pedagogical processes and the development of teaching machines in the broadest sense is one line of technological progress. But there is also their ongoing transformation while transporting them into a "new medium": blackboards and chalk, which allowed students to follow the solution of a problem or the development of ideas, were first replaced by whiteboards and then by smartboards at the beginning of the 21st century.

Overhead projectors allowed instructors to develop an image in their own handwriting like on the chalkboard, but facing the students rather than the chalkboard. PowerPoint slides used for lecturing are a contemporary imitation of transparencies. Lecturers can now show the next slide themselves without needing an assistant in the back of the room to advance the slide tray—which is an improvement over manually removing one slide and putting in the next. The slides themselves can also be seen as an advanced form of wall charts. These completely different technologies are linked by a common pedagogical purpose: to show something and provide additional explanation. Students are not expected to interact with the teaching material.

Another example are technologies that have been reengineered for specific purposes. Word processors that included spelling and grammar checkers already existed in the late 1980s, but projects such as the "Literacy Tutor" (Horton et al., 1990) nevertheless developed word processing programs from scratch to meet specific needs of learners and integrate them into an intelligent tutoring system. There was another round of reengineering when adaptive and intelligent tutoring systems were developed in the early 21st century, often neglecting previous attempts and starting from scratch again.

Technology used in educational settings might also originate from non-educational purposes when its affordances just (seem to) fit the needs, as we show in the following section.

Use of Existing Technology

Today instructors use tablets and digital projectors as sophisticated replication of blackboards and overhead projectors, but tablets were not *designed* for this purpose. Similarly, educators and students alike use word processors for explicit learning activities, such as giving feedback on written drafts or using checkers to learn about spelling and grammar.

The general availability of TV sets—at home and at schools—in the 1950s and 1960s stimulated pedagogical uses of this new medium for educational purposes. The advent of tele-learning brought large-scale attempts at automating parts of teaching: The successive versions of the PLATO systems (Dear, 2017) offered a wide range of facilities meant to support teaching and learning. The main idea was to provide *automated, immediate, and consistent feedback*.[4] The availability of computers and their ever-growing power at the beginning of the 21st century inspired instructors and teaching assistants to use them for repetitive aspects of teaching and grading. Again, one focus was on *automated, immediate, and consistent feedback*, very similar to the attempts of Pressey and Skinner, but without explicitly referencing them. It is no surprise that this resulted in just a contemporary version of the teaching machine and its underlying pedagogical principles—now using (mobile) electronic devices. However, it would be difficult to assign version numbers to teaching machines in a sensible way.

Projects like "One Laptop per Child" (OLPC) in the mid-2000s seemed to be feasible from a technological point of view, but failed both due to design and manufacturing defects of the device and due to a lack of educational support and scenarios (Ames, 2019). The OLPC can serve as a striking example of the failure of efforts driven *solely* by technology, without a solid pedagogical introduction into the educational setting. Development and efforts are needed at both layers of education. The assumption that pedagogy will automatically follow technology has been proven wrong.

Pedagogical Layer

As shown above, the view on the technology layer focuses on tools, objects, and learning products. The view on the pedagogical layer emphasizes settings, methods, and actions of the learning process. We give some examples that may serve as landmarks on the pedagogical layer.

The publication of *E-tivities: The Key to Active Online Learning* by Salmon (2002), a conceptual framework for discussing interactive learning activities, has had a significant impact on the pedagogical layer. Salmon recommends active guidance of online students by means of *e-tivities* to promote the learning competence of any study group. E-tivities, in a nutshell, are online interactions, designed and implemented in the context of a five-stage model. Salmon developed the theoretical framework based on empirical studies in large learning groups at the Open University UK, observing how students repeatedly shaped learning and group behavior in typical activities and phases. The five-stage model provides a framework for classifying e-tivities and thus designing one's study guidance. At the most abstract level, they are technology-agnostic as they focus on interaction with and between students in groups.

Nevertheless, in her seminal book and in later editions and workshops, Salmon constantly refers to current Web technology used for learning and establishes the notion of *e-moderation*. Well-designed assignments and explanations are part of any successful learning process. Her research transferred much of classic group theory into the realm of online education and all its variants. So maybe it would be worth to assign a major version number to this concept on the pedagogical layer?

The integration of contemporary technology into pedagogy requires time. As Hicks & Turner (2013) show for the teaching of writing, the general shift from marking student drafts with a red pen to writing conferences with students using word processors and their feedback features took 30 years—or two generations of instructors—although the underlying technological support had been available much earlier. The authors argue that in the digital age "we do not have decades to catch up to […] change," (Hicks & Turner, 2013, p. 59). They clearly consider technological development as driving force for change in educational settings.

While drawing images on a board and giving explanations is a *teaching activity*, marking passages in texts can be considered a *learning activity*. In its simplest form, the technology needed is a text on paper and a pen (or various pens in different colors). With computers, one can use the digitized text and highlight text parts with appropriate tools, such as PDF viewers, that offer these functionalities as part of their general feature set. Currently, "Hypothes.is"[5] is a prominent web-based platform for annotating texts and sharing the resulting annotations. It is actually advertised as "[…] a new effort to implement an old idea,"[6] making it clear that the project focuses on transporting an established method into a new medium. While annotation is a valid scientific method (Mell & Mahlow, 2021), learning how to annotate is often neglected and reduced to comparing annotations, i.e., the products. One attempt to overcome this obstacle was "tEXtMACHINA" (Hofer et al., 2010), which is unfortunately no longer maintained.

Annotating parts of texts could be seen as an externalization of thought, but it is rarely used for corresponding pedagogical purposes. Sharing annotations reduces this activity to a product-oriented event, without supporting learning as a process. As such, we can compare it to presenting and sharing PowerPoint slides as a digital version of chalkboard images. But in consuming these, one misses the whole process of how the images were developed. The process is hidden, the end product is at the focus of attention, but it does not trigger learning in the same way as if one had followed the process.

The Two Layers Revealed

Remote teaching and learning suddenly became a necessity in Spring 2020, when students and instructors were banned from campuses due to measures to fight Covid-19. The first reactions to this new situation were either driven by technology or by pedagogical considerations. The focus on one layer risks forgetting the other layer, or silently assuming that the other layer would follow; we see both types of failure here.

In Spring 2020 there were simply no time and no resources to transform pedagogy or to at least adapt it to the situation. The over-night shift from familiar face-to-face teaching and learning (maybe enhanced with a few online activities in exemplary blended scenarios) to fully remote and online teaching revealed that there is a strong tendency to just transfer traditional formats into the digital world.

Instructors were desperately looking for *tools* supporting the live broadcasting of old-fashioned lectures to small and large audiences, and mainly turned education into videoconferencing (for a critical view see e.g., Alexander, 2020). Due to the mentally demanding overall situation they wanted to change as little as possible. There also was the need to transport established technology—e.g., boards and slide shows—into the new setting. The "digital transformation" turned out to be "digitization" only: mimicking the face-to-face experience of both instructors (writing on a black or white board and showing slides while lecturing) and students (following the writing on the board, making notes in their physical or digital copies of the slides). It showed the degree to which education still relies on mimicking the "usual" in the "new"—trying to have face-to-face lectures online at the scheduled date and time, covering topics and issues as listed in the syllabus, no matter what. Done this way, the term *digital transformation* in the context of education is a misnomer, as actually only digitization or automation of teaching takes place (Mahlow & Hediger, 2019).

Students and instructors alike soon realized that this approach was not feasible with respect to both layers: bandwidth was not sufficient to support 90 minutes of live streaming when entire universities followed the same approach at the same time—the technology could not fully support the needs. It also turned out that talking to a webcam is actually quite stressful and completely different from speaking to a real audience; students requested asynchronous formats because they had to reorganize their days; interacting with students via the screen is different from receiving a question from a student in the room and giving an answer that makes sense to everyone. Technology at hand did not and does not support a one-to-one equivalent of these interactions in the digital world (see also Richardson, 2020). Remote teaching is different from face-to-face teaching, whether in the form of online-only learning or in the form of blended learning, i.e., mixing online and face-to-face phases. It also revealed that this approach is insufficient and not what students or instructors had hoped for (June, 2020). Hodges et al. (2020) elaborate on the term *emergency remote teaching* and argue that instructors need to stop rushing and take their time to develop learning scenarios that are actually appropriate for the situation at hand, taking both the technological as well as the pedagogical layer into account. They stress that it was simply ignored that "[t]ypical planning, preparation, and development time for a fully online university course is six to nine months before the course is delivered" (Hodges et al., 2020).

After an initial hype around the videoconferencing software Zoom,[7] critical voices drew attention to numerous privacy issues: collection of user data, deep integration of the application into the user's system without informing the user accordingly, an unusual concept of "end-to-end encryption," etc. Surprisingly, there is not much discussion about the pedagogical advantages and disadvantages of videoconferencing for teaching and learning: the pedagogical layer is mostly ignored and technology is used only as a solution to the transmission problem.

Contextualization and Personalization in a Loosely Coupled System

As we have shown above, education is complex and involves both pedagogy and technology. These aspects have been explored by psychologists and computer scientists alike, focusing on interaction of humans and machines in general. As Weizenbaum stressed in a talk held in 1990, the challenge is not how to design and implement "vernünftige Schulsoftware" (reasonable educational software), but how to establish a school system that can use such a system in a reasonable way (Weizenbaum, 2001, p. 95). And even 30 years after his talk, the challenge is still open.

In the 1970s, Rumelhart & Norman (1976) looked at education from a psychological, design-oriented point of view and emphasized that true learning should involve *accretion* (the accumulation of facts), *tuning* (practice to be able to execute skills in an automated way), and *restructuring* (building new structures) (Rumelhart & Norman, 1976, 1981). All three are all but impossible without technology and pedagogy as complementary forces.

A recurring theme in successful teaching and learning experiences is the consideration of the *context* of learning scenarios. Learning should take place in safe environments that allow for trial and error, but at the same time they should be modeled on the "real world" as closely as possible. Simulated worlds (Norman, 1993, p. 37) are thus actually contextualizations of learning.

When people enter a state of flow they become fully engaged, and learning opportunities emerge. Creating such personalized and contextualized scenarios is technically feasible today, but appropriate pedagogical concepts are largely lacking. The question is not so much how to tame general technology to turn it into educational technology, but rather how to activate the pedagogical layer to benefit from the complementary contributions of technology and pedagogy.

Current technological developments, such as datafication (Williamson et al., 2020) and artificial intelligence (AI), provide the foundation for building applications and use cases based on standardized practices and data formats that integrate the context of data and procedures into settings and scenarios that support teaching and learning. Surprisingly, companies like Minerva University[8] currently offer nothing more than just a faster approach to automated, immediate, and consistent feedback—a new version of teaching machines. They collect and mine student data, they run "learning analytics" and make heavy use of data and state-of-the-art machine learning techniques (Kosslyn & Nelson, 2017). There is limited pedagogical development associated with these projects; they merely aim to digitize and digitalize established concepts and automate administrative processes.

Technology alone is never the answer to any real-world problem: it must be seen in the context of development and (intended vs. actual) use. Technology and its affordances clearly are supporting factors. The two layers of education—pedagogy and technology—must be considered in interaction to support and enhance learning activities in an unobtrusive way that engages learners and instructors alike, builds on inherent neuropsychological processes, and uses contextualization to ensure close contact with the real world. Technology and pedagogy complement each other.

Current technological developments, due to digitization, digitalization, and digital transformation, finally permit educators to create contextualized and personalized learning situations and support learners appropriately. We all now have mid-size computing centers in our pockets, but we have to work on how to make best use of it for teaching and learning. One *can* use new technology, fancy apps, and smart tools to get involved in a pedagogically sound way.

In this article, we have proposed a two-layer model of technology and pedagogy to describe the development of education. Complementing technology with established and proven principles of situated, contextualized learning is a prerequisite for its fruitful design and implementation. We hope that the model of loosely coupled layers of technology and pedagogy can serve as a starting point for the necessary discussions.

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1. Translation: "Certain structures, in their long life, become the stable elements of an infinity of generations" (Braudel, 1958/2009, p. 171). ↩
2. See for example a discussion on Twitter on January 12, 2020, starting with a Tweet by Nele Hirsch: https://twitter.com/eBildungslabor/status/1216272813646065664/. ↩
3. See for example https://www.toptools4learning.com, https://cooltoolsforschool.net/, https://edtechdigest.com/category/cool-tools/ or the desperate demands for tools during the Covid-19 pandemic, ignoring aspects of data security or privacy, sometimes even explicitly. ↩
4. See also http://homepage.cs.uiowa.edu/~jones/plato/ and http://friendlyorangeglow.com. ↩
5. https://web.hypothes.is ↩
6. https://web.hypothes.is/about/ ↩
7. https://www.zoom.us ↩
8. https://www.minervaproject.com/ ↩