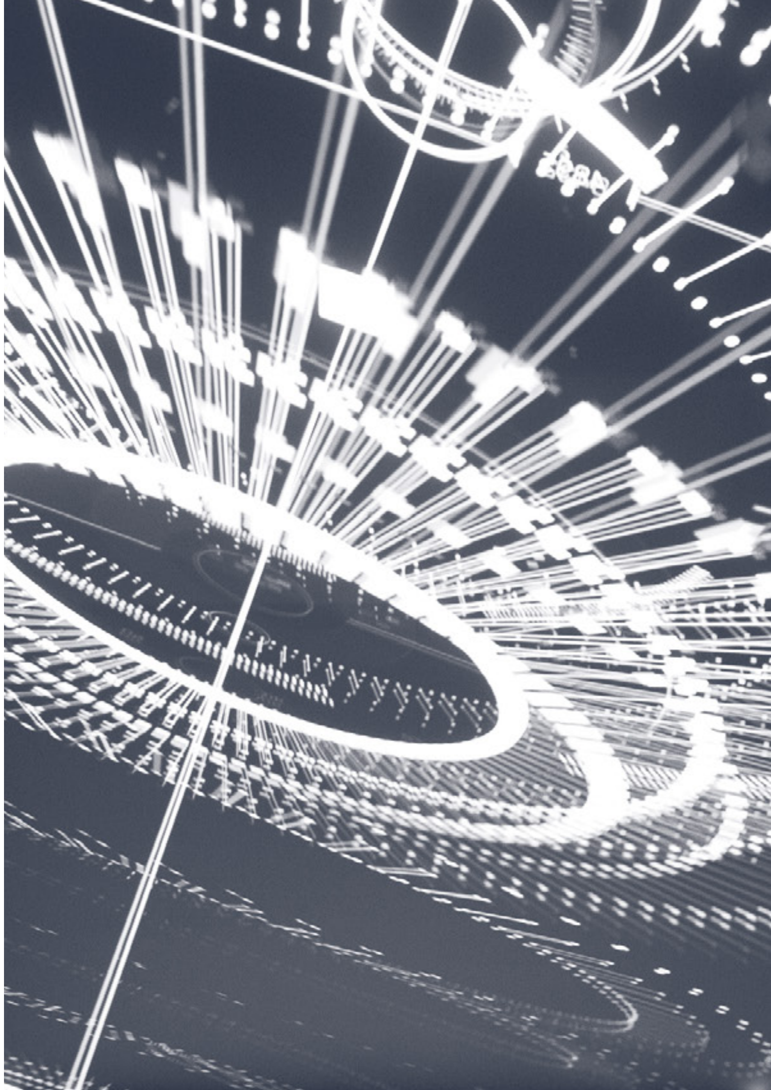
Exploratory study
3/2017

Notions of disruption

A collection of exploratory studies written and commissioned by the Swiss Science and Innovation Council SSIC



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Schweizerischer Wissenschafts- und Innovationsrat
Conseil suisse de la science et de l'innovation
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Swiss Science and Innovation Council

The Swiss Science and Innovation Council

The Swiss Science and Innovation Council SSIC is the advisory body to the Federal Council for issues related to science, higher education, research and innovation policy. The goal of the SSIC, in conformity with its role as an independent consultative body, is to promote the framework for the successful development of the Swiss higher education, research and innovation system. As an independent advisory body to the Federal Council, the SSIC pursues the Swiss higher education, research and innovation landscape from a long-term perspective.

Der Schweizerische Wissenschafts- und Innovationsrat

Der Schweizerische Wissenschafts- und Innovationsrat SWIR berät den Bund in allen Fragen der Wissenschafts-, Hochschul-, Forschungs- und Innovationspolitik. Ziel seiner Arbeit ist die kontinuierliche Optimierung der Rahmenbedingungen für die gedeihliche Entwicklung der Schweizer Bildungs-, Forschungs- und Innovationslandschaft. Als unabhängiges Beratungsorgan des Bundesrates nimmt der SWIR eine Langzeitperspektive auf das gesamte BFI-System ein.

Le Conseil suisse de la science et de l'innovation

Le Conseil suisse de la science et de l'innovation CSSI est l'organe consultatif du Conseil fédéral pour les questions relevant de la politique de la science, des hautes écoles, de la recherche et de l'innovation. Le but de son travail est l'amélioration constante des conditions-cadre de l'espace suisse de la formation, de la recherche et de l'innovation en vue de son développement optimal. En tant qu'organe consultatif indépendant, le CSSI prend position dans une perspective à long terme sur le système suisse de formation, de recherche et d'innovation.

Il Consiglio svizzero della scienza e dell'innovazione

Il Consiglio svizzero della scienza e dell'innovazione CSSI è l'organo consultivo del Consiglio federale per le questioni riguardanti la politica in materia di scienza, scuole universitarie, ricerca e innovazione. L'obiettivo del suo lavoro è migliorare le condizioni quadro per lo spazio svizzero della formazione, della ricerca e dell'innovazione affinché possa svilupparsi in modo armonioso. In qualità di organo consultivo indipendente del Consiglio federale il CSSI guarda al sistema svizzero della formazione, della ricerca e dell'innovazione in una prospettiva globale e a lungo termine.

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Preface by the SSIC

This collection of papers is the result of the exploratory phase of the SSIC's work on the overarching theme of "disruptive change in economy and society by technology and other drivers" from its 2016–2019 Working Programme.[1] During the past few months, the SSIC has committed itself to exploring the notion of disruptive innovation in one of its plenary and in several working-group meetings. With the publication of this collection, the SSIC is pleased to make the results of its exploratory work available to interested readers.

As a first step, the Council decided to compile a definitory discussion based on Christensen's (2000) notion of disruptive innovation. This critical discussion also includes the approach of Henderson and Clark (1990) as well as Gans' (2016) effort to unify the two notions of disruptive innovation. This paper further contains an analysis of the Swiss education, research, and innovation (ERI) landscape and how its actors can influence the emergence of disruptive innovations and how they at the same time are affected by it. In addition, Council members have identified key issues in their November 2016 plenary meeting with regard to the Swiss ERI landscape.

As a second step, the process of digitalisation (including its underlying potentially disruptive technological innovations and business models) was chosen as an illustrative example. The example lends itself to illustration for two reasons: First, it is of high relevance to the Swiss economy, characterised by its high level of technological development and lack of natural resources. Second, because both firms and the labour force are affected by digitalisation, the case is of direct relevance to the Swiss ERI system (with education in particular) and thus the SSIC's field of expertise. In order to better understand how potentially disruptive innovations affect the economy and society, the Council has invited Vivek Wadhwa, professor at Carnegie Mellon University's College of Engineering, to address the SSIC at its November 2016 plenary meeting. A short summary of his keynote speech is presented here in the second paper and the corresponding transcript may be found in the respective appendix.

Finally, the Council was interested in how digitalisation challenges the education system. The SSIC therefore invited Sabine Seufert, professor for Business Education at the University of St. Gallen, to give a keynote speech at its November 2016 plenary meeting. Due to her absence owing to illness, she has been mandated to formulate her considerations on digital competences in a short position paper. At the invitation of the Council's working group, Alexander Repenning, professor for Computer Science Education at the University of Applied Sciences FHNW and the University of Colorado, wrote an introductory comment to this collection's third and final paper. In his comment, he embeds professor Seufert's position paper in the Swiss education system, provides an international comparison, and supplies concrete action items.

Based on these exploratory studies, the Council will continue to examine the effects of potentially disruptive technologies on different Swiss business sectors and society. In exploring how incumbent businesses and start-ups deal with uncertainty, the Council intends to focus on the role of the ERI system's actors in exploiting the positive effects of disruptive innovations and mitigating its negative effects on businesses and society.

1 http://swir.ch/en/programme

Vorwort des SWIR

Diese Sammlung von Arbeiten ist das Resultat der explorativen Studien des SWIR zum übergreifenden Thema «Disruptive Veränderungen in Wirtschaft und Gesellschaft durch Technologie und andere Faktoren» gemäss dem Arbeitsprogramm 2016–2019[2]. In den letzten Monaten beschäftigte sich der SWIR in einer seiner Plenarversammlungen und in mehreren Arbeitsgruppentreffen mit dem Begriff der disruptiven Innovation. Gerne stellt der SWIR nun mit der Veröffentlichung dieser Sammlung die Resultate seiner explorativen Arbeit einer interessierten Leserschaft zur Verfügung.

Als Erstes entschied sich der Rat für eine definitorische Eingrenzung gestützt auf den Begriff der disruptiven Innovation von Christensen (2000). Ausserdem wurden auch der Ansatz von Henderson und Clark (1990) sowie die Bestrebungen von Gans (2016) zur Vereinheitlichung der beiden Definitionen der disruptiven Innovation kritisch betrachtet. Diese Arbeit enthält zudem eine Analyse der schweizerischen Bildungs-, Forschungs- und Innovationslandschaft (BFI-Landschaft) und untersucht, wie deren Akteure disruptive Innovationen einerseits beeinflussen können und andererseits auch davon betroffen sind. Überdies bestimmten die Ratsmitglieder in der Plenarversammlung vom November 2016 Kernthemen betreffend die Schweizer BFI-Landschaft.

Als Zweites wurde der Prozess der Digitalisierung (einschliesslich der diesem zugrundeliegenden potenziell disruptiven technologischen Innovationen und Geschäftsmodelle) als anschauliches Beispiel gewählt. Das Thema eignet sich aus zwei Gründen zur Veranschaulichung: Erstens ist es von grosser Relevanz für die Schweizer Wirtschaft, die durch einen hohen technologischen Entwicklungsgrad und fehlende natürliche Ressourcen geprägt ist. Zweitens sind sowohl die Arbeitgeber als auch die Arbeitnehmenden von der Digitalisierung betroffen, weshalb das Beispiel für das BFI-System (insbesondere die Bildung) unmittelbar von Bedeutung ist und somit in den Fachbereich des SWIR fällt. Um besser zu verstehen, wie potenziell disruptive Innovationen die Wirtschaft und die Gesellschaft beeinflussen, lud der Rat Vivek Wadhwa, Professor des Carnegie Mellon University's College of Engineering, als Redner an die Plenarsitzung des SWIR vom November 2016 ein. Der zweite Beitrag enthält eine kurze Zusammenfassung seines Vortrags und das entsprechende Transkript ist im Anhang zu finden.

Schliesslich befasste sich der Rat mit den Herausforderungen, die die Digitalisierung für das Bildungssystem mit sich bringt. Dazu lud er Sabine Seufert, Professorin für Wirtschaftspädagogik der Universität St. Gallen, für einen Vortrag an die Plenarversammlung vom November 2016 ein. Aufgrund ihrer krankheitsbedingten Abwesenheit wurde sie gebeten, ihre Ansichten zu digitalen Kompetenzen in einem kurzen Positionspapier festzuhalten. Alexander Repenning, Professor für Informatische Bildung der Fachhochschule Nordwestschweiz FHNW und der Universität von Colorado, verfasste auf Einladung der Arbeitsgruppe des Rates einen einleitenden Kommentar zum dritten und letzten Beitrag der Sammlung. Darin bettet er das Positionspapier von Professorin Seufert in das Schweizer Bildungssystem ein, zieht einen internationalen Vergleich und zeigt konkrete Handlungsfelder auf.

Ausgehend von diesen explorativen Studien wird der Rat die Auswirkungen potenziell disruptiver Technologien auf verschiedene Industrien und die Schweizer Gesellschaft weiter erforschen. Bei seiner Untersuchung, wie etablierte Unternehmen und Start-ups mit Unsicherheit umgehen, will sich der Rat auf die Rolle der BFI-Akteure bei der Nutzung der positiven Effekte und bei der Milderung der negativen Auswirkungen disruptiver Innovationen auf die Wirtschaft und die Gesellschaft konzentrieren.

2 http://swir.ch/de/arbeitsprogramm

Préface du CSSI

Ce recueil de rapports est le résultat de la phase exploratoire du travail du CSSI sur la thématique globale des «changements disruptifs dans l'économie et la société induits par les technologies et par d'autres facteurs» de son programme de travail 2016–2019[3]. Au cours des derniers mois, le CSSI s'est consacré à l'exploration de la notion d'«innovation disruptive» lors de l'une de ses séances plénières et de plusieurs réunions de son groupe de travail. Avec la publication de ce recueil, le CSSI est ravi de pouvoir faire partager aux lecteurs intéressés le résultat de son travail d'exploration.

Premièrement, le conseil a décidé de mener une discussion définitionnelle en s'appuyant sur la notion d'«innovation disruptive» de Christensen (2000). Cette réflexion critique inclut également l'approche de Henderson et Clark (1990), ainsi que l'effort entrepris par Gans (2016) pour unifier les deux notions d'«innovation disruptive». Ce rapport comprend en outre une analyse du paysage suisse de la formation, de la recherche et de l'innovation (FRI), et de la manière avec laquelle ses acteurs peuvent influencer l'émergence d'innovations disruptives et comment celles-ci les touchent simultanément. Lors de leur séance plénière de novembre 2016, les membres du conseil ont également identifié des questions clés à propos du paysage FRI suisse.

Deuxièmement, l'exemple représentatif choisi est le processus de numérisation (y compris ses innovations technologiques potentiellement disruptives et ses modèles d'affaires). L'exemple se prête bien à la démonstration pour deux raisons: il revêt tout d'abord une grande importance pour l'économie suisse, qui est caractérisée par son niveau élevé de développement technologique et son manque de ressources naturelles. Ensuite, étant donné que les entreprises et la population active sont touchées par la numérisation, le cas concerne directement le système FRI suisse (la formation en particulier), qui est le domaine de compétence du CSSI. Pour mieux comprendre à quel point les innovations potentiellement disruptives touchent l'économie et la société, le conseil a invité Vivek Wadhwa, professeur au Carnegie Mellon University's College of Engineering, à prononcer un discours lors de la séance plénière du CSSI en novembre 2016. Un bref résumé de son discours liminaire est présenté dans ce second rapport, et la transcription correspondante se trouve dans l'annexe respective.

Enfin, le conseil s'est intéressé aux défis que pose la numérisation au système de formation. Le CSSI a donc invité Sabine Seufert, professeure de la chaire de Business Education à l'Université de Saint-Gall, à prononcer un discours liminaire lors de sa séance plénière de novembre 2016. N'ayant pas pu y participer pour cause de maladie, il lui a été demandé de formuler ses considérations sur les compétences numériques dans une brève prise de position. A l'invitation du groupe de travail du conseil, Alexander Repenning, professeur de la chaire de Computer Science Education à l'Université des sciences appliquées du Nord-Ouest de la Suisse (FHNW) et à la University of Colorado, a rédigé une introduction au troisième et dernier rapport de ce recueil. Dans son commentaire, il intègre la prise de position de la professeure Seufert dans le système de formation suisse, dresse une comparaison internationale et propose des mesures concrètes.

Sur la base de ces études exploratoires, le conseil continuera à examiner les effets des technologies potentiellement disruptives sur différents secteurs d'activité et la société suisse. En explorant la manière dont les entreprises et les start-up titulaires font face à l'incertitude, le conseil entend se concentrer sur le rôle des acteurs du système FRI en exploitant les effets positifs des innovations disruptives et en compensant ses répercussions négatives sur les entreprises et la société.

3 http://swir.ch/fr/programme-de-travail

Prefazione del CSSI

Questa raccolta di articoli è frutto della fase preliminare del lavoro del CSSI sul vasto tema dei «cambiamenti disrumpenti nell'economia e nella società indotti da nuove tecnologie ed altri fattori», contenuto nel programma di lavoro 2016–2019.[4] Nel corso degli ultimi mesi il CSSI ha analizzato il concetto di innovazione rivoluzionaria in una delle sedute plenarie e in diverse riunioni del gruppo di lavoro. Con la pubblicazione della raccolta vengono messi a disposizione dei lettori interessati i risultati di questo lavoro preliminare.

In una prima fase il Consiglio ha deciso di porre le basi della discussione, avvalendosi della nozione di innovazione rivoluzionaria di Christensen (2000) e tenendo conto dell'approccio di Henderson e Clark (1990) e del tentativo di Gans (2016) di unificare le due definizioni di tale concetto. Il documento contiene inoltre un'analisi del sistema svizzero ERI (educazione, ricerca e innovazione) e illustra come gli operatori possono influenzare ed essere al contempo influenzati dalla comparsa di innovazioni radicali. A novembre 2016, in occasione della seduta plenaria, i membri del Consiglio hanno individuato alcune questioni essenziali riguardanti questo sistema.

In una seconda fase il processo di digitalizzazione (insieme alle innovazioni tecnologiche potenzialmente rivoluzionarie su cui si fonda e ai modelli imprenditoriali) è stato scelto come esempio illustrativo: innanzitutto in quanto di estrema importanza per l'economia svizzera, notoriamente caratterizzata da elevato livello di sviluppo tecnologico e scarsità di risorse naturali, ma anche perché la digitalizzazione influisce su aziende e forza lavoro e quindi interessa direttamente il sistema ERI (in particolare l'educazione) e il settore di competenza del CSSI. Per una migliore comprensione dell'effetto delle innovazioni potenzialmente rivoluzionarie sull'economia e sulla società, il Consiglio ha invitato a parlare alla sessione plenaria di novembre 2016 Vivek Wadhwa, professore presso la facoltà di ingegneria della Carnegie Mellon University. Il secondo articolo contiene un breve riassunto del suo discorso e in appendice la relativa trascrizione.

Al fine di approfondire il tema delle sfide della digitalizzazione per il sistema educativo, il CSSI ha invitato Sabine Seufert, prof.ssa di pedagogia economica presso l'Università di San Gallo, a tenere un discorso alla seduta plenaria di novembre 2016. A causa della sua assenza per malattia, le è stato richiesto di esporre le proprie considerazioni sulle competenze digitali in un breve documento di sintesi. Su invito del gruppo di lavoro del Consiglio, Alexander Repenning, professore informatica presso l'Università di scienze applicate FHNW e l'Università del Colorado, ha scritto un commento introduttivo al terzo e ultimo articolo di questa raccolta, in cui inquadra le considerazioni della prof.ssa Seufert nel sistema educativo svizzero, fa un confronto a livello internazionale e fornisce proposte di azione concrete.

Sulla base di questi studi preliminari, il Consiglio continuerà a esaminare gli effetti delle tecnologie potenzialmente rivoluzionarie sui diversi settori e sulla società in Svizzera. Analizzando il modo in cui le aziende e le start-up gestiscono l'incertezza, il Consiglio intende concentrarsi sul ruolo degli operatori ERI nello sfruttamento degli effetti positivi delle innovazioni rivoluzionarie e nell'attenuazione degli effetti negativi sulle imprese e sulla società.

4 http://swir.ch/it/programma-di-lavoro

Executive summary

Each of this summary's section covers one of the aforementioned papers included in this collection.

Disruptive innovation

Disruptive innovation (DI) is a paradoxical phenomenon: Well-managed companies fail because they keep doing what made them successful, including continuously investing in innovative technologies. At the same time, DI introduces products to the market that are easier to use and cheaper, increasing customers' utility.

Leading companies do fail either because they cannot absorb new knowledge or production logics, or because their cost structure prevents it. The "demand-side disruption involves an established firm missing a certain kind of technological opportunity, supply-side disruption arises when an established firm becomes incapable of taking advantages of a technological opportunity" (Gans, 2016, p. 104).

General managerial strategies on how to deal with the disruptive effects of such innovations are the fostering of organisational resilience and the appropriate framing of possibly disruptive developments (i.e., addressing the situation with urgency but in a constructive and open manner). Further, managerial literature suggests specific strategies geared towards demand- and supply-side DIs:

- Demand-side: Double down (heavy investments in existing products and services – although popular, this strategy ultimately fails, as it does not acknowledge the nature of disruption); wait and double up (continuously catering to existing customers while simultaneously trying to establish oneself in the new market, i.e. self-disruption); wait and buy up (continuously catering to existing customers while buying promising market entrants to acquire potentially disruptive innovators); wait and give up (winding up the company as long as it is profitable in order to pass on the created value to shareholders).

- Supply-side: Integrated company structure (guaranteeing a flexible organisational structure to be able to understand, absorb, and integrate a supply-side innovation); ownership of key complementary assets (as such assets are vital to a product, no matter their logic or architecture); strong corporate identity (a clear and abstract understanding what product a company is offering to its customers).

The education, research, and innovation (ERI) system plays a central role in creating and dealing with potential DIs:

- Providers in the ERI system supply education and thus contribute to a more resilient future work force and management which is more adaptive to change. Further, through investments in research and frictionless knowledge and technology transfer (KTT) platforms as well as means for commercialisation the ERI system can help firms to efficiently exploit the merits of DI.

- Intermediaries, such as non-profit organisations, may provide flexible solutions in the context of uncertainty inherent in DIs. They can also frame potential threats in order for policy actors to release enough resources for providers to create progressive and constructive solutions.

- Policy actors are central in shaping the framework conditions for a productive exploitation of potentially disruptive technologies without stressful transitional phases for economy and society.

The SSIC has discussed several key issues concerning the Swiss ERI system and potential DIs and identified nine central problems. Among other things, these involve

- fostering of skills and competencies complementary to the potentially disruptive technologies,

- the role of KTT schemes,

- the agility of small and medium-sized enterprises (SMEs) in dealing with DI,

- the social and ethical implications of such innovations, and

- whether increasingly fostering information and communication technology (ICT) comes at the cost of neglecting other disciplines.

Digitalisation

Recent developments in advanced robotics, artificial intelligence, and machine learning have sparked a wave of anxiety based on the perceived threats they pose to jobs thus far performed by humans.

Prognoses of the impact these technological developments might have vary greatly. However, there does seem to be agreement that, where possible, public policy should mitigate the negative effects of job displacement and potential increases in inequality of wealth distribution that could result. This is especially important as wealth distribution affects social cohesion.

Although Switzerland has had a steady labour share of gross domestic product (GDP) and no polarisation in job creation based on skill levels, the threats automation poses (based on the digitalisation of processes) should still be taken seriously. Simultaneously, these developments provide an opportunity as they may offer a solution to Switzerland's sluggish productivity growth.

Whether the technologies which are driving the current trend of digitalisation are truly going to be disruptive to the Swiss economy and society will only become evident in hindsight. It is nevertheless important to invest into making the labour force and businesses more resilient in dealing with uncertainties. This not only includes investing into education and applying appropriate managerial strategies, but also fostering sociodiversity as a prerequisite to a thriving modern society (as argued by Helbing et al., 2016).

Efforts already underway by Swiss ERI actors are diverse, as an exploratory mapping in this study shows.

Digital competences

Among the many effects digitalisation will have on our way of working and living, the augmentation of human skills through machines is the most central. The current debate should therefore not focus on the substitution of human workforce.

To understand how humans and in the end society interact with machines, Professor Seufert presents a framework proposed by MIT Associate Professor Iyad Rahwan: Moving from a simple "human-in-the-loop" (formulating goals, constraints, expectations, etc., for machines to perform tasks) towards a "society-in-the-loop". This refers to the embedding of ethical values, laws, and social norms into the way autonomous systems (artificial intelligence, etc.) perform their tasks.

To accomplish a well-performing human- and society-in-the-loop, digital competences are necessary. These competences should be established as transversal competences into the education system based on a "spiral curriculum" framework. Digital competences consist of digital literacy, digital citizenship, and finally the development of personality in a digital society.

Current empirical results with regard to digital competences of students are alarming – especially given the current lack of a national digital competence framework in Switzerland:

- In terms of computer and information literacy, Swiss students do not exhibit above average competences in comparison to other EU countries and almost 30% do not exceed the lowest level of competence.
- There is some evidence that Swiss students have deficits particularly in information literacy.
- Data supports the existence of a socio-economic and gender gap in digital skills.
- Although students are digital natives, they lack sufficient Internet skills.
- Students' objective literacy is considerably lower than their subjective self-assessed literacy.
- Due to a very low response rate, no analysis of teacher competences from the ICILS 2013 study is publicly available for Switzerland.

Professor Seufert concludes her paper with six points: 1. Raising awareness for complementary competences; 2. Development of a national digital competence framework; 3. Establishment of formative assessments, integrated assessment systems and a graduation portfolio system; 4. Enabling do-it-yourself learning in educational institutions; 5. Capacity building through the development of digital competences of teachers; 6. Further research in the field of digital competences to close the society-in-the-loop gap.

Executive Summary

In diesem Executive Summary wird pro Abschnitt jeweils eine der vorgängig erwähnten Arbeiten dieser Sammlung beschrieben.

Disruptive Innovation

Disruptive Innovation (DI) ist ein paradoxes Phänomen: Gut geführte Unternehmen scheitern, weil sie an dem festhalten, was ihnen Erfolg gebracht hat, selbst wenn sie ständig in innovative Technologien investiert haben. Gleichzeitig bringt DI neue Produkte auf den Markt, die benutzerfreundlicher, kostengünstiger und damit für die Kundinnen und Kunden nützlicher sind.

Führende Unternehmen scheitern, weil sie entweder neue Erkenntnisse oder Produktionslogiken nicht umsetzen können oder weil ihre Kostenstruktur dies verhindert. Laut Gans betrifft die nachfrageseitige Disruption ein etabliertes Unternehmen, das eine bestimmte technologische Chance verpasst, während eine angebotsseitige Disruption dann eintritt, wenn ein etabliertes Unternehmen nicht mehr in der Lage ist, eine technologische Chance zu seinem Vorteil zu nutzen (Gans, 2016, S. 104).

Allgemeine Managementstrategien sehen für den Umgang mit disruptiven Auswirkungen von entsprechenden Innovationen u.a. die Stärkung der organisatorischen Resilienz und die Schaffung eines geeigneten Rahmens für potenziell disruptive Entwicklungen vor (z.B. die Situation mit der nötigen Dringlichkeit, aber auf konstruktive und offene Weise angehen). Die Managementliteratur schlägt zudem spezifische Strategien vor, die auf nachfrage- oder angebotsseitige DI ausgerichtet sind:

- Nachfrageseitig: «double down» (massive Investitionen in bestehende Produkte und Dienstleistungen; diese zwar beliebte Strategie versagt aber letztlich, da sie das Wesen der Disruption verkennt); «wait and double up» (fortlaufende Versorgung der bestehenden Kundschaft und gleichzeitiger Versuch, sich im neuen Markt zu etablieren, d.h. Selbstdisruption); «wait and buy up» (fortlaufende Versorgung der bestehenden Kundschaft und gleichzeitiger Kauf vielversprechender neuer Marktteilnehmer, um potenziell disruptive Innovatoren zu akquirieren); «wait and give up» (Abwicklung des Unternehmens, solange dieses noch rentabel ist, um den generierten Mehrwert an das Aktionariat weiterzugeben).

- Angebotsseitig: integrierte Unternehmensstruktur (gewährleistet eine flexible Organisationsstruktur, um eine angebotsseitige Innovation zu verstehen, zu übernehmen und zu integrieren); im Besitz wichtiger komplementärer Vermögenswerte (da solche Vermögenswerte unabhängig von ihrer Logik oder Architektur für ein Produkt essenziell sind); starke Corporate Identity (ein klares und abstraktes Verständnis davon, welche Art von Produkt ein Unternehmen seiner Kundschaft anbietet).

Das Bildungs-, Forschungs- und Innovationssystem (BFI-System) spielt eine zentrale Rolle bei der Schaffung potenzieller DI und dem Umgang damit:

- Anbieter im BFI-System stellen Bildungsangebote bereit und tragen damit zur Resilienz künftiger Arbeits- und Führungskräfte bei, die sich Veränderungen besser anpassen können. Darüber hinaus kann das BFI-System durch Investitionen in die Forschung und Plattformen für einen reibungslosen Wissens- und Technologietransfer (WTT) sowie in Vermarktungsinstrumente Unternehmen dabei helfen, die Vorteile von DI effizient zu nutzen.

- Intermediäre wie beispielsweise nicht gewinnorientierte Organisationen bieten im unsicheren Umfeld von DI gegebenenfalls flexible Lösungen. Sie können durch das Framing potenzieller Gefahren dafür sorgen, dass politische Akteure genügend Ressourcen zur Verfügung stellen, mit denen Anbieter wiederum fortschrittliche und konstruktive Lösungen entwickeln können.

- Politische Akteure spielen eine wesentliche Rolle bei der Schaffung der Rahmenbedingungen für eine produktive Nutzung potenziell disruptiver Technologien ohne mühsame Übergangsphasen für Wirtschaft und Gesellschaft.

Der SWIR hat verschiedene Kernthemen betreffend das Schweizer BFI-System und potenzielle DI diskutiert und neun Hauptprobleme identifiziert. Dazu gehören:

- die Förderung von ergänzenden Fähigkeiten und Kompetenzen im Zusammenhang mit potenziell disruptiven Technologien,

- die Rolle von WTT-Modellen,

- die Gewandtheit von kleinen und mittleren Unternehmen (KMU) im Umgang mit DI,

- die sozialen und ethischen Auswirkungen solcher Innovationen und

- die Frage, ob eine zunehmende Förderung der Informations- und Kommunikationstechnologien (IKT) auf Kosten anderer Fächer geht.

Digitalisierung

Neuste Entwicklungen in der modernen Robotik, der künstlichen Intelligenz und dem maschinellen Lernen haben grosse Ängste bezüglich der Gefahren ausgelöst, die diese für bisher von Menschen ausgeführte Arbeiten darstellen.

Die Prognosen zu den Auswirkungen dieser technologischen Entwicklungen gehen stark auseinander. Einig scheint man sich indessen darin, dass die öffentliche Politik die negativen Effekte der Jobverdrängung und einer möglicherweise daraus resultierenden Ungleichverteilung des Vermögens mildern sollte. Dies ist besonders wichtig, da die Vermögensverteilung den sozialen Zusammenhalt beeinflusst.

Auch wenn der Anteil des Arbeitseinkommens am BIP in der Schweiz bisher stabil war und sich bei der Schaffung von Arbeitsplätzen keine Polarisierung aufgrund des Kompetenzniveaus abzeichnet, gilt es, die Gefahren der Automatisierung (durch die Digitalisierung von Prozessen) ernst zu nehmen. Gleichzeitig stellen diese Innovationen auch eine Chance dar und könnten der Schweiz Lösungen für ihr träges Produktivitätswachstum bringen.

Ob die Technologien, die den gegenwärtigen Digitalisierungstrend antreiben, für die Schweizer Wirtschaft und Gesellschaft tatsächlich disruptiv sein werden, lässt sich erst im Nachhinein beurteilen. Trotzdem braucht es Investitionen, um die Arbeitskräfte und die Unternehmen im Umgang mit Unsicherheiten resilienter zu machen. Es bedarf allerdings nicht nur Investitionen in die Bildung und geeigneter Führungsstrategien, sondern auch der Förderung von gesellschaftlicher Diversität als Voraussetzung für eine blühende moderne Gesellschaft (gemäss Helbing et al., 2016).

Eine exploratorische Karte in diesem Studienbericht zeigt, wie vielfältig die bereits laufenden Bemühungen der BFI-Akteure sind.

Digitale Kompetenzen

Bei den zahlreichen Auswirkungen, die die Digitalisierung auf unsere Arbeits- und Lebensweise haben wird, steht die Erweiterung der menschlichen Fähigkeiten durch Maschinen an erster Stelle. Die aktuelle Debatte sollte sich deshalb nicht auf den Ersatz der menschlichen Arbeitskraft fokussieren.

Um zu verstehen, wie der Mensch und letztlich die Gesellschaft mit Maschinen interagieren, stellt Professorin Seufert ein Rahmenwerk von Iyad Rahwan, ausserordentlicher Professor am MIT, vor: Die Entwicklung geht vom einfachen «Mensch in der Schleife» («human-in-the-loop»: Formulierung von Zielen, Vorgaben, Erwartungen etc. für Maschinen, die Aufgaben ausführen sollen) in Richtung einer «Gesellschaft in der Schleife» («society-in-the-loop»). Gemeint ist hier der Einbezug von ethischen Werten, Gesetzen und sozialen Normen in die Art, wie autonome Systeme (künstliche Intelligenz etc.) ihre Aufgaben erledigen.

Für ein leistungsfähiges Mensch- oder Gesellschaft-in-der-Schleife-System sind digitale Kompetenzen gefordert. Diese Kompetenzen sollten als fachübergreifende Kompetenzen in das Bildungssystem aufgenommen werden, und zwar mithilfe eines Spiralcurriculums. Digitale Kompetenz besteht aus digitalen Kenntnissen, digitaler Bürgerschaft und schliesslich der Persönlichkeitsentwicklung in einer digitalen Gesellschaft.

Aktuelle empirische Resultate zur digitalen Kompetenz von Schülerinnen und Schülern sind alarmierend – insbesondere da in der Schweiz ein nationaler Rahmenlehrplan für digitale Kompetenz momentan fehlt:

- Bei den Computer- und Informatikkenntnissen schneiden die Schweizer Schülerinnen und Schüler im Vergleich zu anderen EU-Ländern lediglich durchschnittlich ab, und fast 30 % von ihnen kommen nicht über die tiefste Kompetenzstufe hinaus.

- Es gibt Hinweise darauf, dass Schweizer Schülerinnen und Schüler insbesondere in der Informatikbildung Lücken aufweisen.

- In Bezug auf digitale Kenntnisse scheinen sozioökonomische und geschlechterbezogene Ungleichheiten zu existieren.

- Obwohl die Schülerinnen und Schüler «Digital Natives» sind, mangelt es ihnen an ausreichenden Internetkenntnissen.

- Die objektive Kompetenz der Schülerinnen und Schüler ist deutlich tiefer als die von ihnen selbst subjektiv wahrgenommene Kompetenz.

- Aufgrund einer sehr tiefen Rücklaufquote ist für die Schweiz keine Analyse der Kompetenzen von Lehrpersonen aus der Studie ICILS 2013 öffentlich verfügbar.

Professorin Seufert stellt am Ende ihres Positionspapiers sechs Forderungen in den Raum: 1. Das Bewusstsein für ergänzende Kompetenzen stärken; 2. Einen nationalen Rahmenlehrplan für digitale Kompetenz entwickeln; 3. Formative Beurteilungen, integrierte Beurteilungssysteme und «Graduation Portfolio»-Systeme einführen; 4. Do-it-yourself-Lernen in Bildungsinstitutionen ermöglichen; 5. Durch die Entwicklung von digitaler Kompetenz bei den Lehrpersonen Kapazitäten aufbauen; 6. Forschung zu digitaler Kompetenz vertiefen, um die Kluft zur «Gesellschaft in der Schleife» zu schliessen.

Résumé

Chacune des sections de ce résumé couvre l'un des rapports susmentionnés inclus dans ce recueil.

Innovation disruptive

L'innovation disruptive est un phénomène paradoxal: des entreprises bien gérées sont en situation d'échec, car elles continuent à faire ce qui a fait leur succès, y compris investir continuellement dans des technologies innovantes. Simultanément, l'innovation disruptive introduit sur le marché des produits moins chers et plus faciles à utiliser, augmentant l'utilité pour les clients.

Certaines entreprises leader échouent soit parce qu'elles ne parviennent pas à absorber les nouvelles connaissances ou la logique de production, soit parce que leur structure des coûts les en empêche. La «disruption au niveau de la demande implique une entreprise établie qui passe à côté d'un certain type d'opportunité technologique, tandis que la disruption au niveau de l'offre survient lorsqu'une entreprise établie devient incapable de tirer parti d'une opportunité technologique» (Gans, 2016, p. 104).

Les stratégies générales de gestion sur la façon d'affronter les effets perturbateurs de telles innovations consistent à encourager la résilience organisationnelle et à élaborer de manière appropriée des développements potentiellement perturbateurs (c'est-à-dire gérer la situation en urgence, mais d'une manière constructive et ouverte). En outre, la littérature managériale propose des stratégies spécifiques axées sur des innovations disruptives au niveau de la demande et de l'offre:

- Au niveau de la demande: doubler la mise (bien que la stratégie consistant à réaliser des investissements importants dans des produits et services existants soit populaire, elle se solde par un échec, car elle ne tient pas compte de la nature de la disruption); attendre et doubler (s'occuper continuellement des clients existants tout en essayant de s'établir sur le nouveau marché, c'est-à-dire auto-disruption); attendre et acheter (s'occuper continuellement des clients existants tout en achetant des arrivants sur le marché prometteurs dans le but d'acquérir des innovateurs potentiellement perturbateurs); attendre et renoncer (liquider l'entreprise tant qu'elle est rentable pour transmettre la valeur créée aux actionnaires).

- Au niveau de l'offre: structure d'entreprise intégrée (garantit une structure organisationnelle flexible pour pouvoir comprendre, absorber et intégrer une innovation au niveau de l'offre); possession d'actifs complémentaires clés (car de tels actifs sont essentiels pour un produit, quelle que soit leur logique ou architecture); identité d'entreprise forte (une compréhension claire et abstraite du produit qu'une entreprise offre à ses clients).

Le système de formation, de recherche et d'innovation (FRI) joue un rôle clé dans la création et le traitement des innovations potentiellement disruptives:

- Les fournisseurs du système FRI forment et contribuent donc à une population active future plus résiliente et à un management plus souple face au changement. En outre, via des investissements dans la recherche et des plateformes de transfert de savoir et de technologie (TST) sans heurts ainsi que des moyens de commercialisation, le système FRI peut aider les entreprises à exploiter efficacement les mérites de l'innovation disruptive.

- Des intermédiaires, tels que des organisations sans but lucratif, peuvent fournir des solutions flexibles face à l'incertitude inhérente aux innovations disruptives. Ils peuvent également encadrer les menaces potentielles afin que des acteurs politiques libèrent suffisamment de ressources pour que les fournisseurs puissent créer des solutions progressives et constructives.

- Ces acteurs occupent un rôle central dans l'élaboration des conditions-cadre pour une exploitation productive de technologies potentiellement disruptives, sans que l'économie et la société n'aient à passer par des phases de transition stressantes.

Le CSSI a discuté de plusieurs questions clés à propos du système FRI suisse ainsi que des innovations disruptives et a identifié neuf problèmes principaux impliquant, entre autres:

- l'encouragement des aptitudes et des compétences complémentaires aux technologies potentiellement disruptives;

- le rôle des projets TST;

- la souplesse des petites et moyennes entreprises (PME) dans la gestion de l'innovation disruptive;

- les implications sociales et éthiques de telles innovations;

- le fait de savoir si encourager de plus en plus les technologies de l'information et de la communication (TIC) revient à négliger d'autres disciplines.

Numérisation

Des développements récents en robotique avancée, en intelligence artificielle et en apprentissage automatique ont déclenché une vague d'anxiété causée par des menaces présumées qu'elles font peser sur les tâches réalisées jusqu'à présent par les humains.

Les prévisions sur l'impact possible de ces développements technologiques ont beaucoup varié. Toutefois, on s'accorde à dire que la politique publique doit – lorsque c'est possible – compenser les effets négatifs de la suppression d'emplois et les augmentations potentielles de l'inégalité de la distribution des richesses qui pourraient en résulter. Ceci est particulièrement important, car la distribution des richesses a un effet sur la cohésion sociale.

Bien que la Suisse ait connu une part des revenus du travail stable dans le produit intérieur brut (PIB) et aucune polarisation dans la création d'emplois basée sur les niveaux de compétence, les menaces que fait peser l'automatisation (sur la base de la numérisation des processus) doivent toujours être prises au sérieux. Simultanément, ces développements sont une opportunité, car ils pourraient offrir une solution à la croissance lente de la productivité de la Suisse.

Le fait de savoir si les technologies qui sont le moteur de la tendance actuelle de la numérisation vont véritablement perturber l'économie et la société suisses ne deviendra évident que rétrospectivement. Il est cependant important de réaliser des investissements pour rendre la population active et les entreprises plus résilientes lorsqu'elles doivent faire face à des incertitudes. Il s'agit d'investir dans la formation et d'appliquer des stratégies de management appropriées, mais aussi d'encourager la sociodiversité comme un prérequis à une société moderne florissante (ce que soutiennent Helbing et al., 2016).

Les efforts déjà déployés des acteurs du système FRI suisse sont variés, comme le montre l'inventaire exploratoire de cette étude.

Compétences numériques

L'augmentation des compétences humaines via des machines est l'effet principal parmi tous ceux que la numérisation aura sur notre manière de travailler et de vivre. Le débat actuel ne devrait donc pas se concentrer sur la substitution de la main-d'œuvre humaine.

Afin de comprendre comment les humains, et en fin de compte la société, interagissent avec les machines, la professeure Seufert présente un cadre proposé par Iyad Rahwan, professeur associé au MIT: passer du simple «humain dans la boucle» (formulation d'objectifs, de contraintes, d'attentes, etc. pour que les machines réalisent des tâches) à une «société dans la boucle». Cela concerne l'intégration de valeurs éthiques, de lois et de normes sociales dans la manière dont les systèmes autonomes (intelligence artificielle, etc.) réalisent leurs tâches.

Il est nécessaire de disposer de compétences numériques pour réaliser un modèle d'humain et de société dans la boucle performant. Celles-ci doivent être établies comme des compétences transversales dans le système éducatif sur la base d'un cadre de «programme en spirale». Les compétences numériques englobent la maîtrise du numérique, la citoyenneté numérique et le développement de la personnalité dans une société numérique.

Les résultats empiriques actuels relatifs aux compétences numériques des étudiants sont alarmants, en particulier compte tenu de l'absence d'un cadre national de compétences numériques en Suisse:

- en matière de maîtrise informatique et de l'information, les étudiants suisses ne possèdent pas de compétences au-dessus de la moyenne par rapport à d'autres pays européens et près de 30% d'entre eux ne dépassent pas le niveau de compétences le plus faible;
- il a été prouvé que les étudiants suisses ont des lacunes notamment en maîtrise de l'information;
- les résultats soutiennent l'existence d'un fossé socio-économique et entre les sexes au niveau des compétences numériques;
- bien qu'ayant grandi dans le monde numérique, les étudiants ont une maîtrise insuffisante de l'Internet;
- la maîtrise objective des étudiants est beaucoup moins bonne que la maîtrise subjective qu'ils ont évaluée eux-mêmes;
- en raison d'un taux de réponse très faible, aucune analyse des compétences des professeurs tirée de l'étude ICILS 2013 n'est disponible publiquement en Suisse.

La professeure Seufert conclut son rapport par les six points suivants: 1. sensibiliser davantage aux compétences complémentaires; 2. développer un cadre national de compétences numériques; 3. établir des évaluations formatives, des systèmes d'évaluation intégrés et un système de portefeuille de fin d'études; 4. permettre d'apprendre par soi-même dans les établissements d'enseignement; 5. renforcer les capacités en développant les compétences numériques des professeurs; 6. continuer les recherches dans le domaine des compétences numériques pour combler le fossé de la «société dans la boucle».

Riassunto

Ogni sezione di questa sintesi tratta uno degli articoli precedentemente citati inclusi in questa raccolta.

Innovazione rivoluzionaria

L'innovazione rivoluzionaria (IR) è un fenomeno paradossale: imprese ben gestite falliscono poiché continuano a fare ciò che ha portato al loro successo, incluso investire costantemente in tecnologie innovative. Al contempo l'IR comporta l'immissione sul mercato di prodotti più facili da utilizzare e più convenienti, incrementando l'utilità per i clienti.

Aziende leader falliscono perché non sono in grado di assimilare nuove conoscenze o logiche di produzione o perché la struttura dei costi non lo consente. «L'arresto della domanda deriva dalla perdita di una determinata opportunità tecnologica da parte di un'azienda consolidata mentre l'interruzione dell'offerta è determinata dall'incapacità di un'azienda consolidata di trarre vantaggio da un'opportunità tecnologica» (Gans, 2016, p. 104).

Per affrontare gli effetti perturbatori di tali innovazioni possono essere adottate strategie generali quali la promozione della resilienza organizzativa e una gestione appropriata di sviluppi potenzialmente rivoluzionari (ad es. affrontando la situazione con urgenza, in modo costruttivo e aperto). La letteratura manageriale propone specifiche strategie per far fronte all'IR dal punto di vista della domanda e dell'offerta.

- Domanda: aumento della posta in gioco (con consistenti investimenti in prodotti e servizi esistenti, una strategia che, sebbene diffusa, è destinata a fallire poiché non riconosce la natura dell'IR); attesa e raddoppio degli investimenti (continuare a soddisfare i clienti esistenti e al contempo cercare di affermarsi nel nuovo mercato); attesa e acquisizione (continuare a soddisfare i clienti esistenti e al contempo acquisire nuove aziende promettenti per entrare in possesso di innovazioni potenzialmente rivoluzionarie); attesa e resa (liquidare l'azienda finché è redditizia al fine di trasmettere il valore creato agli shareholer).

- Offerta: struttura aziendale integrata (garantire una struttura organizzativa flessibile al fine di comprendere, assimilare e integrare un'innovazione a livello di offerta); possesso di vantaggi chiave complementari (essenziali per un prodotto, a prescindere dalla loro logica o architettura); forte identità societaria (comprensione chiara e astratta del prodotto offerto da un'azienda ai propri clienti).

Il sistema ERI (educazione, ricerca e innovazione) riveste un ruolo centrale nella creazione e nella gestione di potenziali IR:

- operatori ERI offrono corsi di formazione, contribuendo a sviluppare una forza lavoro più tenace e una gestione più flessibile ai cambiamenti. Inoltre, attraverso investimenti in ricerca, agevoli piattaforme per il trasferimento di conoscenze e tecnologia (TCT) e mezzi di commercializzazione, il sistema ERI può aiutare le aziende a sfruttare in modo efficiente i pregi delle IR;

- intermediari, quali organizzazioni non profit, possono fornire soluzioni flessibili in situazioni di incertezza dovute a IR. Inoltre possono individuare potenziali minacce affinché gli attori politici stanzino risorse sufficienti per consentire agli operatori di sviluppare soluzioni progressive e costruttive;

- gli attori politici rivestono un ruolo centrale nella definizione delle condizioni per uno sfruttamento efficiente di tecnologie potenzialmente rivoluzionarie, eliminando fasi transitorie stressanti per l'economia e la società.

Il CSSI ha discusso diverse questioni chiave concernenti il sistema svizzero ERI e potenziali IR, individuando nove problemi principali, che riguardano:

- la promozione di abilità e competenze complementari alle tecnologie potenzialmente rivoluzionarie;

- il ruolo di schemi TCT;

- la prontezza delle piccole e medie imprese (PMI) nella gestione delle IR;

- le implicazioni sociali ed etiche di tali innovazioni;

- il rischio di trascurare altri ambiti per promuovere le tecnologie dell'informazione e della comunicazione (TIC).

Digitalizzazione

I recenti sviluppi nella robotica avanzata, nell'intelligenza artificiale e nell'apprendimento automatico sono stati percepiti come una minaccia per i lavori finora svolti dall'uomo.

Nonostante le previsioni sull'impatto di tali sviluppi siano divergenti, sembra esservi consenso sul compito della politica pubblica nell'attenuare, ove possibile, gli effetti negativi della soppressione di posti di lavoro e del potenziale aumento della disuguaglianza economica, che a sua volta incide sulla coesione sociale.

Sebbene in Svizzera la quota della manodopera sul PIL sia rimasta stabile e non vi sia stata alcuna polarizzazione nella creazione di posti di lavoro in base alle competenze, la minaccia posta dall'automazione (derivante dalla digitalizzazione dei processi) deve essere presa sul serio. Al contempo questi sviluppi potrebbero offrire una soluzione alla lenta crescita della produttività. Sarà possibile stabilire solo a posteriori se le tecnologie alla base dell'attuale trend di digitalizzazione saranno veramente rivoluzionarie per l'economia e la società svizzera. È tuttavia importante rendere la forza lavoro e le aziende più resistenti alle incertezze, non solo investendo nella formazione e attuando strategie gestionali adeguate, ma anche promuovendo la sociodiversità in quanto prerogativa di una società moderna e prospera (come affermato da Helbing et al., 2016).

Gli operatori ERI hanno già intrapreso diverse azioni in tal senso, come mostrato dalla mappa in questo studio.

Competenze digitali

L'effetto principale della digitalizzazione sul modo di vivere e lavorare è rappresentato dall'aumento delle capacità umane attraverso l'uso di macchine. L'attuale dibattito non dovrebbe quindi essere incentrato sulla sostituzione della forza lavoro.

Per capire l'interazione tra uomo/società e macchine, la prof.ssa Seufert presenta una struttura proposta da Iyad Rahwan, professore associato presso il MIT, che passa da un semplice «human in the loop», dove l'uomo stabilisce obiettivi, limiti ecc. per il funzionamento delle macchine, a una «society in the loop», che integra valori etici, leggi e norme sociali nella gestione dei sistemi automatici (intelligenza artificiale ecc.).

Per implementare correttamente questi due approcci sono necessarie competenze digitali, che dovrebbero essere inserite nel sistema educativo come disciplina trasversale sulla base di un «curriculum a spirale». Tali competenze sono l'alfabetizzazione e la cittadinanza digitale nonché lo sviluppo della personalità in una società digitale.

I risultati empirici sul livello degli studenti in quest'ambito sono allarmanti, soprattutto data l'attuale mancanza di un quadro di competenze digitali in Svizzera:

- in termini di alfabetizzazione informatica, gli studenti non presentano competenze superiori alla media rispetto ad altri Paesi UE e quasi il 30% non supera il livello più basso;
- è emerso che gli studenti presentano deficit in particolare nell'alfabetizzazione informatica;
- vi è consenso sull'esistenza di un divario socio-economico e di genere nelle competenze digitali;
- sebbene gli studenti siano figli dell'era digitale, non possiedono abilità informatiche sufficienti;
- l'alfabetizzazione oggettiva degli studenti è nettamente inferiore a quella percepita;
- a causa del tasso molto ridotto di risposta, non è stata resa pubblica alcuna analisi dello studio ICILS 2013 sulle competenze dei docenti in Svizzera.

La prof.ssa Seufert conclude il suo articolo rilevando sei punti fondamentali: 1. sensibilizzazione sulle competenze complementari; 2. sviluppo di un quadro nazionale di competenze digitali; 3. istituzione di verifiche formative, sistemi di valutazione integrati e portafoglio qualifiche; 4. ammissione dell'autoapprendimento in istituzioni di formazione; 5. aumento delle capacità attraverso lo sviluppo delle competenze digitali dei docenti; 6. ulteriori ricerche nell'ambito delle competenze digitali per colmare la lacuna della «society in the loop».

Disruptive innovation

Exploratory study written by the Swiss Science and Innovation Council SSIC

1

1.1
Introduction

The notion of disruptive innovation (DI), as originally presented by Christensen (2000), offers a theoretical framework which allows one to understand and potentially address uncertainties which arise as a result of the development of a special kind of technical innovations. These DI may fundamentally change the usage or functionality of certain products, the market position of businesses, or even entire industries. Although much of the managerial literature from innovation studies focuses on the disruptive effects for businesses, these innovations also empower start-ups and create utility for consumers.

Given the increasing use (but also misuse) uf the term disruption, this paper critically discusses the notion of DI and how it is different from regular competition. This discussion is intended to lay a sound basis for the SSIC's future discussion of DI in the context of its overarching topic "disruptive change in economy and society by technology and other drivers". The paper specifically addresses DI's place in innovation studies, business strategies to deal with it, and finally assesses where actors in the Swiss education, research, and innovation (ERI) system have room for manoeuvre and instruments to influence the emergence of DI and means to deal with its effects on the economy and society.

1.2
Definition and literature

The term disruptive innovation was coined by Christensen (2000) in his seminal The Innovator's Dilemma. Christensen defines innovation as a change in technology,[5] itself understood as concerned with production processes which transform inputs into outputs (such as goods or services). Changes in technology may include using new components in a product, new hard or soft skills applied in production, or the architecture of how a good or service is designed or assembled.

Christensen (2000) introduced DI as a reason why good companies fail, as they continue to do what made them successful: Follow good management practices, listen carefully to customers, and invest into new technologies, thus increasing customer satisfaction and revenues. Govindarajan and Kopalle (2006, p. 13) summarise the following five points which characterise DI:

1. The innovation underperforms on the attributes mainstream customers value.

2. The new features offered by the innovation are not valued by the mainstream customers.

5 This definition does not necessarily coincide with the SSIC's understanding (SSIC, 2015b).

3. The innovation typically is more simple and cheaper and is offered at a lower price than existing products.

4. At the time of its introduction, the innovation appeals to a low-end, price-sensitive customer segment, thus limiting the profit potential for incumbents.[6]

5. Over time, further developments improve the innovation's performance on the attributes mainstream customers value to a level where the innovation begins to attract more of these customers.

Following the fifth characteristic, incumbent firms usually start losing market share and/or leadership due to their inability to offer a similar good or service with the additional attributes customers suddenly seek and value (these attributes are sometimes also called "drivers", see Paap & Katz, 2004). Such attributes or drivers are characteristics of a product or service that appeal to customers, derived from functionality, reliability, convenience, and/or price.[7] The emergence of a new, dominant attribute ultimately leads to disruption for incumbents. Thus, the disruptiveness of the innovation does not manifest itself immediately, which may have added to some of the confusion or misuse of the term (Christensen, Raynor, & McDonald, 2015).

Schmidt and Druehl (2008) had already confirmed this in noting that, because disruption develops over time, DI itself actually has a non-disruptive nature. Instead, they characterise it as being a kind of "low-end encroachment". Companies offering goods or services based on a DI slowly start capturing market shares first from low-end and then gradually towards high-end customers. DI therefore often starts in a fringe market or a completely detached (niche) market and then diffuses upwards. Paap and Katz (2004) show that the event of disruption (by definition) depends on the existing market mechanisms failing, which means disruption ultimately depends on the response by incumbents. The three cases in which a DI can manifest are:

The maturing of technology in a dominant driver:

- Assuming customers care most about speed and power consumption of data storage devices, flash drives are now more reliable than hard disk drives (HDD).

- The maturing of the dominant driver leading to another, existing driver to become dominant: Customers suddenly primarily chose their HDD based on size, not storage capacity as the product's previously dominant driver.

- A change in the environment that creates a new, previously non-existing driver: Climate change may represent such a change, which creates new drivers, for instance in the tourism industry. Winter tourism may suddenly seize to be about snow sports.

As DI offers features initially not valued by mainstream customers, it "heralds a change in the basis of competition" (Christensen, 2000, p. 219). This means that DI is a marketing rather than a laboratory challenge. The concept of DI also does not say anything about the technological nature of the innovation. As Govindarajan and Kopalle (2006) put it, the differentiation between incremental and radical innovation is concerned with the technological dimension of innovation: its radicalness.

disruptive	radical (no)	radical (yes)
(yes)	incremental & disruptive innovations – from smaller to bigger HDD – from regular to low-cost airlines	radical & disruptive innovations – from HDD to flash drives – from cell phone/laptop to smart phone
(no)	incremental & sustaining innovations – from lower- to higher-capacity HDD – from two- to three-blade shaver	radical & sustaining innovations – from turboprops to jet engines – from horse-drawn vehicles to cars[b]

Figure 1.1. Examples of different types of innovation[a]

a Henderson and Clark (1990) present a 2x2 matrix and differentiate between incremental, modular, architectural, and radical innovation. This differentiation, however, is based on other dimensions than disruptiveness and radicalness.

b Christensen (2000) points out that the first car was a luxury item and did not disrupt the transportation market. Only the mass-produced car was a disruptive innovation.

6 Christensen (2000) uses the term "incumbent" as a description for a market leader, thus not in the common, political sense.

7 In this order, these four factors are known as the "buying hierarchy" as developed by Windermere Associates and cited in Christensen (2000).

DI based on incremental innovation is sometimes referred to as "low-end", while a DI based on a radical innovation is labelled "high-end". Such high-end DIs may also sell at a higher price than existing products (Govindarajan & Kopalle, 2006). Technological innovations which do not disrupt firms or markets are called sustaining innovations. These again may be of an incremental or radical technical nature. Figure 1.1 gives examples of all four forms of innovations.

A central issue of DI is that, by definition, it is not foreseeable. A DI slowly encroaches from niche or fringe markets and only becomes disruptive when incumbent firms start to lose competitive advantages in their existing markets. Therefore, whether an innovation is truly disruptive is a question of time and response by other firms. As various scholars have pointed out, this post-hoc definition poses a problem, since it seems to make predicting DIs impossible and thus unusable for managerial decisions (e.g. Danneels, 2004). Still, some researchers have tried to come up with ex-ante measures to identify potential DIs (Govindarajan & Kopalle, 2006) or to predict DIs (Sood & Tellis, 2011).

Henderson and Clark (1990) suggested a different form of disruption, not in the product components but in the architecture of production (e.g., architectural innovation). However, Gans (2016) shows this can be subsumed under the term DI. While he refers to changes in product components as demand-side DI, architectural innovation stands for supply-side DI. This distinction[8] is important, as both forms of DI ask for different managerial and organisational responses.

1.2.1
Demand-side DI

The well-known example of a demand-side DI is the introduction of HDD into the computer industry, as discussed by Christensen (2000). Market actors in the HDD industry had the knowledge and would have been able to produce the smaller drives, but their existing customers and organisations in the company's value chain only cared about storage capacity, and seemed relatively indifferent about the size of the drives. Meanwhile, new market players were marketing and selling the smaller drives to a niche market. Instead of focusing on high-margin customers using room-filling mainframe computers, they targeted lower-end users of minicomputers. Over time, the capacity of the smaller drives increased and incumbents started losing customers to the new market players. Because their capacity had increased, smaller disks also began to satisfy the needs of the older high-margin customers. This finally drove many older companies out of the market: They were not able to quickly enough make up for their lack of interest and investment in developing the smaller HDDs.

This was neither due to bad management nor to failing to anticipate the new technologies: The existing high-margin customers initially simply did not want to buy the new product. Marketing the smaller disks to a new niche market was risky, only promised low margins, and had limited potential in terms of market share. Thus, demand-side DI is not characterised by the unwillingness or inability of incumbents to introduce a new technology. The problem lies in the companies' cost structure and that erroneous incentives or prognoses may be generated if one only listens to one's existing customers.

Typically, companies try to move up-market, which can help to generate high margins and profitability. Moving the other way is counter-intuitive, risky, and may only pay off in the long run: It puts short- and medium-term profits as well as market share at risk. Companies have tended to cater to the needs of their existing customers and therefore are not willing or able to cater to potential, new customers in fringe or even detached markets. Danneels (2004) has criticised this as a firm's shallow understanding of their customers, not a problem of customer orientation per se.

1.2.2
Supply-side DI

Supply-side DI similarly disrupts existing markets and drives incumbents with good management practices or large market share out of business. The supply-side refers to a product's architecture and its production process, not its components. Here the problem lies in the inability of firms to adjust their organisational structures in order to be able to absorb and integrate the logic of new architectures.

The iPhone is a prominent example. Mobile phones, portable digital cameras, e-mail applications, portable .mp3 players, and internet-access devices all already existed. Additionally, the iPhone was too expensive to be a demand-side DI but it nevertheless acted in a disruptive manner in the industry.

The main reason was its new dominant design. Combining existing technologies altered the architecture that had been in use for mobile communication and internet-access devices (including laptops). Henderson and Clark (1990) called this architectural innovation, and pointed out that changes in a product's architecture can render existing, established knowledge and processes within a company obsolete. It can be very difficult to respond to such forms of innovation, even if they are anticipated in advance (see the case of the Blackberry producer Research in Motion). Supply-side DIs are not a problem of marketing innovative technologies to new markets.

8 Markides (2006) further divides DI into three categories: disruptive technological innovation, business model innovation, and product innovation. He stresses that disruptive business model innovations differ from the other two. The present study confines itself to only examining demand- and supply-side DI. This is supported by Christensen et al. (2015), who identify changes in business models as a core feature of disruptive innovators, but not as a category on its own.

The challenge instead lies in understanding the new architecture and rearranging internal processes in a company accordingly. This often requires a more comprehensive understanding of what goods or services a company is offering and thus its corporate identity.

Christensen et al. (2015, p. 50) call the iPhone a DI on the grounds that its business model is new. Including apps is a radical change inasmuch as it has built "a facilitated network connecting application developers with phone users". This means that in this case, architectural und business model innovations are closely related.

Is Uber a disruptive innovation?

The worldwide success of Uber has drawn much attention and generated controversy. By connecting customers to drivers via app, it challenges taxi businesses. Using modern mobile communication technology and decentralised production seems to make Uber a DI, but is it?

According to Christensen et al. (2015), the answer is no, at least in the sense of a demand-side DI. Uber was neither the first to address previous non-consumers, nor did it gain its initial market shares by addressing low-end customers. It did not introduce new attributes but has simply become successful by delivering a better and less expensive solution to existing customers. This is simple competition and therefore a sustaining innovation.

However, taxi companies function in a heavily regulated environment, and this may have slowed innovation and competition for too long. That taxi companies face sudden competition by Uber may be a sign that they are not well-managed firms. Uber therefore is not disrupting, but is instead winning the competition by offering a superior product. Whether this sudden shift stems from exploiting a juridical loophole is not relevant for the distinction between disruptive and sustaining innovation. However, changes in the regulatory environment may lead to the emergence of DIs (Blind, 2016).

1.3 Strategies

Companies are the primary focus of the managerial and scientific literature which discusses strategies for how to deal with DI; government, other policy actors and the labour force are often neglected, lacunae, which will be addressed in Section 1.4 of this paper. In addition to strategies specifically geared towards one of the two subforms of DI, however, scholars have discussed and proposed various strategies to make firms more resilient in disruptive environments. These general strategies, summarised in Subsection 1.3.1, may overlap with the latter two subsections.

1.3.1 General strategies

General strategies include organisational resilience and the productive framing of the situation.

— Organisational resilience: Defined by Hamel and Välikangas (2003, p. 53) as the "ability to dynamically reinvent business models and strategies as circumstances change", organisational resilience is about "having the capacity to change before the case for change becomes desperately obvious". According to them, becoming resilient is connected with four challenges: cognitive, strategic, political, and ideological. Some of these overlap with the strategies subsequently discussed, such as self-disruption or a more integrated company structure.

  Lampel, Bhalla, and Jha (2014) see a correlation between organisational resilience and both structural flexibility and slack. Transferring decision-making authority downwards and outwards also increases resilience. They name employee-owned business (EOB) as a governance structure that promotes resilience. EOBs lend stability to an economy, in the form of employment and employee productivity, in times of crises. Lampel et al. (2014, p. 70f.) further show that "EOBs are more likely to support pioneering of innovations".

  Lengnick-Hall, Beck, and Lengnick-Hall (2011, p. 244) differentiate between two views of resilience. One is the ability to quickly return to the pre-crisis state, while the other "goes beyond returning to established benchmarks … enabling a firm to leverage its resources and capabilities not only to resolve current dilemmas but to exploit opportunities and build a successful future". They define three dimensions of organisational resilience: cognitive, behavioural, and contextual and show how human resource management policy is important in fostering the company's abilities in these dimensions.

Limnios, Mazzarol, Ghadouani, and Schilizzi (2014) differentiate between two opposing manifestations of resilience: offence (adaptation) or defence (resistance) to disturbance. A high degree of resilience that is desirable from a stakeholder point of view is connected with adaptability and a balanced approach between exploring and exploiting situations (see also Osiyevskyy & Dewald, 2015). However, a high degree of resilience that is not desirable is known as rigidity and is connected to organisational denial. In extreme forms, it may even lead to company failure.[9] Thus, resilience might not only be a strategic answer to DI, but in a negative form possibly also its cause. In contrast, Vogus and Sutcliffe (2007, p. 3420) exclude rigidity from the concept of resilience. In their understanding resilience "counteracts tendencies toward threat-rigidity by treating disruptive events and persistent strain as opportunities rather than threats".

- Framing: In a similar manner, Gilbert and Bower (2002) stress that the framing of a situation (here, specifically DI) shapes the form of response and strategy a company will adopt. They argue that a situation should initially be assessed as a threat in order to "free up" much needed resources. However, in subsequently dealing with the situation, the DI should be treated as an opportunity to allow for reactions that are not defensive but creative, sensible, progressive, and forward-looking. They suggest several ways to do so: "building a separate organisation where it's possible to reframe it as an opportunity; funding the new business in stages as new markets emerge rather than all at once; and continuing to pay attention to the old business" (Gilbert & Bower, 2002, p. 101).

1.3.2

Strategies for demand-side DI (see Gans, 2016)

- Double down: This strategy simply describes heavy investments in existing products and services when facing possible disruption. Although this is a strategy chosen by many actors to secure existing high margins, it will ultimately fail, as it does not acknowledge the new dominant driver.
- Wait and double up: This strategy includes two things: Continuously cater to existing customers and invest in sustaining innovations, while simultaneously trying to establish oneself in the new market. Given the problem of existing cost structures, Christensen (2000) suggests this could be achieved through creating an independent but firm-owned spin-off. If the innovation is truly disruptive, the initial spin-off may guarantee the survival of the mother company at a later stage. The company becomes self-disruptive, so to speak. Self-disruption can be achieved through either takeover by or integration of the initial spin-off. It is noteworthy that such an integration poses new managerial challenges.
- Wait and buy up: Instead of establishing its own spin-off, firms buy promising market entrants to acquire potentially disruptive innovators, while running them as independent companies. This, however, comes at a price premium in contrast to the previous strategy.
- Wait and give up: This will not guarantee company survival, but may be very reasonable nevertheless. In theory, the purpose of companies is to maximise net present value, not ensure survival. Therefore, if a company faces disruption, it may be reasonable to wind itself up as long as it is profitable and pass the created value along. Slowly running the company down will destroy its value.

1.3.3

Strategies for supply-side DI (see Gans, 2016)

- Integrated company structure: To understand, absorb, and integrate architectural innovations, a company's organisational structure must be flexible. Based on Vertesi (2015), Gans (2016) gives the example of team Excel vs team PowerPoint in the context of a NASA mission. While team Excel is highly specialised and effective in data collection, its specialisation makes it unable to obtain a holistic view. Team PowerPoint, by contrast, is oriented towards shared resources and a consensus approach, but in collecting data it misses a great deal. Still, its analysis is deeper, reflecting the trade-off between specialised and deep knowledge. While companies like team PowerPoint may miss opportunities, they remain flexible and better able to absorb new dominant designs. However, it comes at the price of reduced performance, effectiveness, and possibly the absence of market leadership.

9 This is also known as the Icarus paradox, where a company's success becomes its own pitfall (Miller, 1992).

- Ownership of key complementary assets: Such assets, in this term introduced by Teece (1986), may guarantee the survival of a firm through several waves of supply-side DIs. The reason is that they are of vital importance to a product, no matter the architecture. Gans (2016) discusses the example of Mergenthaler, a company originally active in the Linotype business.[10] The industry underwent several disruptions. However, due to owning the rights to widely used fonts, Mergenthaler survived these disruptions. Although not a direct response, this case is helpful for understanding which factors can shield a company from disruption.

- Strong corporate identity: A clear and abstract understanding of what product a company is offering to its customers and what utility customers derive from this product is essential for surviving waves of disruptions. Although Kodak heavily invested in research into digital photography, the company failed to understand that digitalisation also meant vast visual data storage capacity and not simply an alternative way of capturing images. In contrast, Fujifilm redefined its corporate identity. Thanks to its existing product range, it was better positioned to consider new business models. This, together with its strong corporate identity, allowed the firm to survive and prosper in the age of digitalisation.

10 The original research was conducted by Tripsas (1997).

1.4 Room for manoeuvre

In order to understand what role the ERI system plays in the emergence and dealing with potentially DIs, it is necessary to take a closer look at the type of actors involved. This eventually facilitates the analysis of their room for manoeuvre. The central actors in the Swiss ERI system can be categorised into three types: providers, intermediaries, and policy actors. All types of schools, universities, research institutions, and research and development enterprises are providers. Policy actors and public administrations, at the national and local level, belong to the third category. Intermediaries, usually organised as associations or private foundations,[11] fall between these two types (SSIC, 2015a). The ERI system thus includes actors from public institutions, firms, different levels of government, and non-profit organisations (NPOs). It can thus play multiple roles in dealing with DI: acting as its source, mitigating its negative, or profiting from its positive effects. The ERI system as a whole may itself be affected by DI.

ERI actors can facilitate the productive exploitation of potentially disruptive technologies. This can be done by helping both start-ups and established firms to stay ahead of the curve (thereby not becoming victims of DI). ERI actors also can provide private individuals with the necessary knowledge and skill-set to deal with technological innovations in a way that prevents them from becoming truly disruptive, by, for example, making their jobs obsolete.[12]

The ERI system is vital in creating added value and increasing productivity and wealth in Switzerland. It can also address the effects the new technologies have on diversity, equality, and sustainability. In their "Digital Manifesto" Helbing et al. (2016) for instance stress that:

> In the future, those countries will be leading that reach a healthy balance between business, government and citizens. This requires networked thinking and the establishment of an information, innovation, product and service "ecosystem". In order to work well, it is not only important to create opportunities for participation, but also to support diversity. Because there is no way to determine the best goal function: should we optimise the gross national product per capita or sustainability? Power or peace? Life expectancy or satisfaction? Often enough, what would have been better is only known after the fact. By allowing the pursuit of various different goals, a pluralistic society is better able to cope with the range of unexpected challenges to come.[13]

11 These are the most common forms of non-profit organisations (NPOs) in Switzerland.

12 Tugwell (1931) called technological unemployment "occupational obsolescence", as it was "impossible and undesirable to prevent technological change".

13 Excerpt from the official English translation, available at: https://www.researchgate.net/profile/Dirk_Helbing/publication/303813069_Behavioural_Control_or_Digital_Democracy_-_A_Digital_Manifesto/links/5755309208ae10d9337a47a2.pdf.

If there is a genuine disruption which may ultimately also cause widespread technological unemployment (due to automation for instance), with humans becoming less important as the suppliers of labour, education will play an even more important role. Although empirical analyses have thus far found no long-lasting effects on unemployment by past technological changes (see for instance Feldmann, 2013), this may not be true of future changes in technology (Danaher, 2017). Floridi (2014) stresses that education will be key in helping people to use their time in meaningful ways and to ensure social cohesion.

In the extreme case where a collapse of demand and high concentration of wealth are expected, the ERI system will not be able to solve this by itself, as the task of redistribution[14] is not within its scope of action. Nevertheless, the ERI system can add constructively to the discussion in weighing the alternatives and mitigating the negative effects of possible winner-take-most economies. Still, as the labour share increases with level of education/qualification, the problem of inequality in income distribution is indirectly a problem of inequality in job qualifications, and this is in the ERI system's purview.

1.5 Instruments

DIs emerge from different sources and ultimately affect many different actors in an economy and society. The effects of a DI, which go beyond economic dimensions, are initially felt through markets as well as the flow of money, products, and resources. To understand which instruments are available to ERI actors, it is necessary to understand how disruption is transmitted and how actors are connected.

The following analysis is not intended as policy recommendation but rather as an effort to map the available instruments.

1.5.1 Method of analysis

The circular flow model (CFM) is used in economic theory to illustrate how resources and products are exchanged between market participants (and thus their flow). This model will be subsequently used in a hypothetical exploration of DI's transmission channels and allows to show where the actors can influence economic and social outcomes.

The basic CFM model (see Figure 1.2) includes three actors (firms, government, households) and two markets (product market, resource market):

- Firms produce goods and sell them on the product market, while they acquire inputs for production on the resource market (capital, labour, land, and entrepreneurship).
- The government[15] regulates markets, raises taxes from both firms and households, supplies public goods, uses resources, and consumes goods and services (public procurement).
- The households include not only the buyers (consumers) of goods and services on the product market, but also the providers of the necessary resources for production. In return, households receive compensation in the form of wages, interests, rent, dividends, etc. over the resource market.

14 For example, through a guaranteed basic income, a negative income tax, a robot tax, corporate tax based on degree of shareholder diversity, higher equity ratios in pension funds, or other means are discussed in Brynjolfsson and McAfee (2014); Delvaux (2016); Ford (2015); Kaplan (2015).

15 As this is an economic model, the term "government" is used rather freely and stands as a collective term for several public sector representatives as well as political authorities.

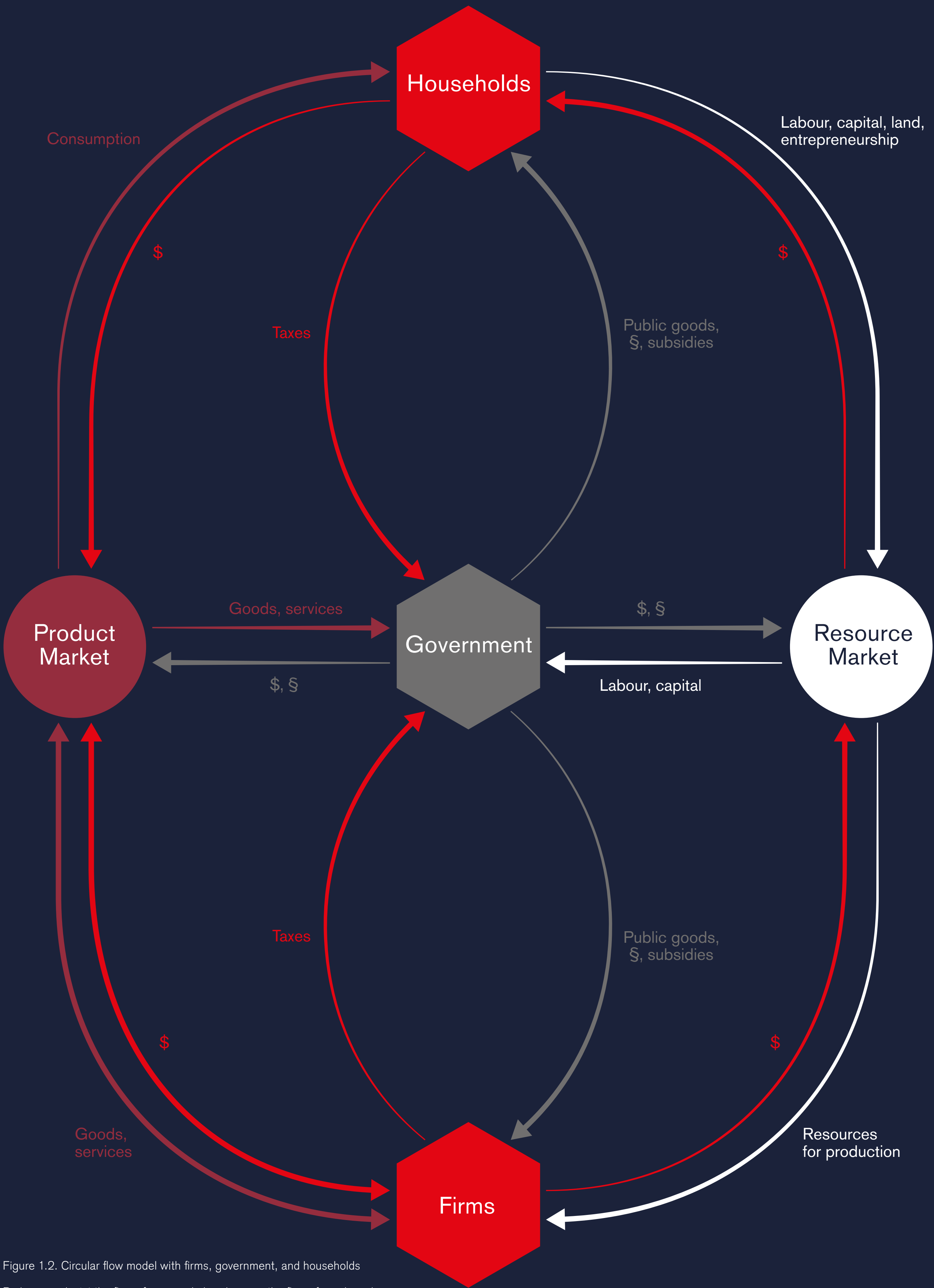

Figure 1.2. Circular flow model with firms, government, and households

Red arrows depict the flow of money, dark red arrows the flow of goods and services, and white arrows the flow of resources. Grey arrows mark the flow of government actions; laws and regulations are indicated by a silcrow.

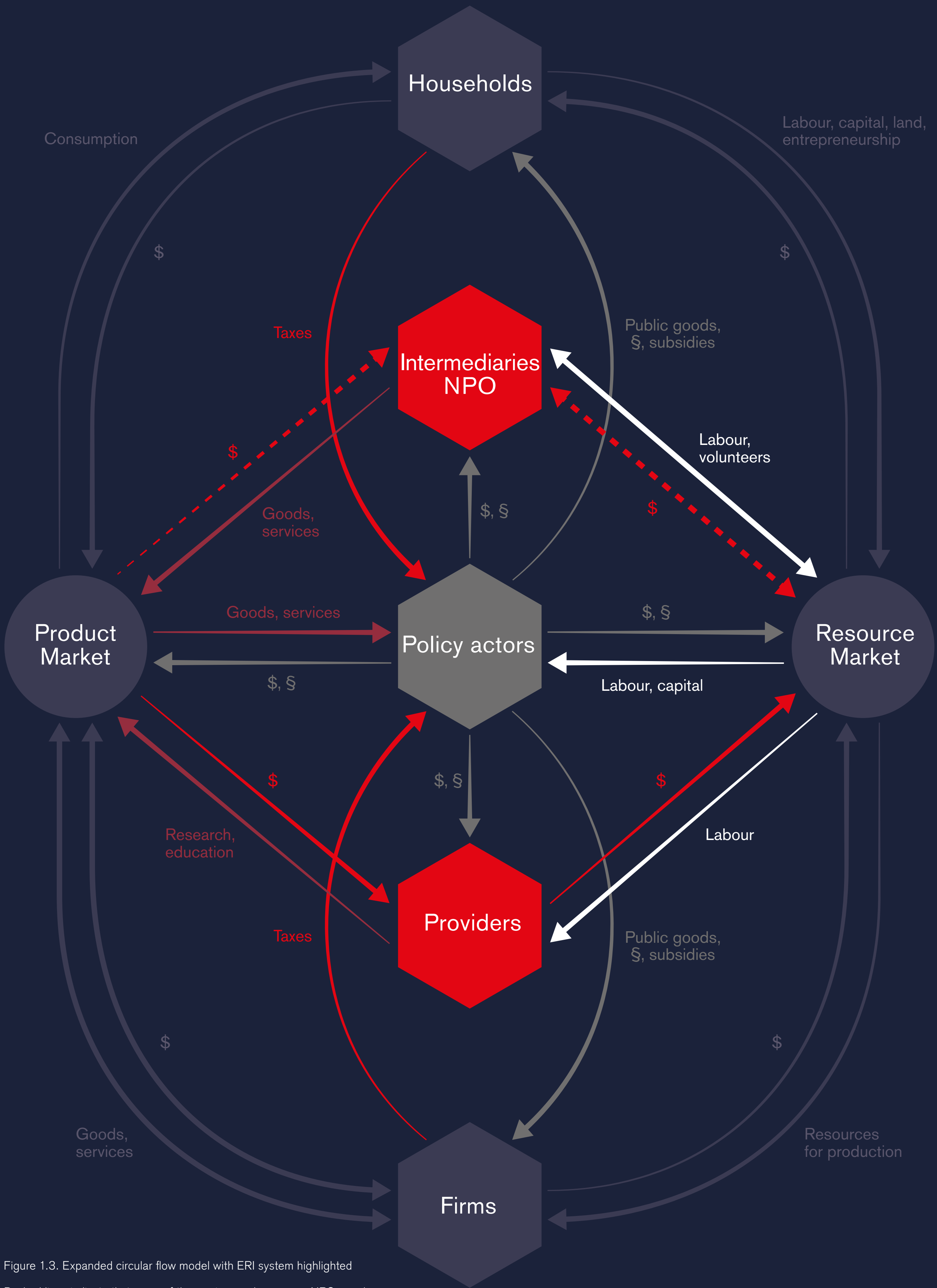

Figure 1.3. Expanded circular flow model with ERI system highlighted

Dashed lines indicate that some of the services and resources NPOs produce or use may be free of charge (free services to beneficiaries/members, volunteer work, funding, donations, etc.)

The CFM is an analysis of the flow of economic resources and products. As the ERI system, with its providers, intermediaries, and policy actors, produce different forms of outputs and employ different resources, it is necessary to amend this model (see Figure 1.3):

- Policy actors are assumed to be performing the same tasks as the government (raising taxes, regulating markets, supplying public goods) as presented in Figure 1.2.
- Providers of education and public research are primarily funded by the government, create and disseminate knowledge, supply education to households, acquire resources on the resource market, and provide services such as further education or contract research on the product market.
- Intermediaries and NPOs act as representatives for firms, higher education institutions (HEI), and households (advocacy), make and receive donations (as a resource), supply goods and services to their members and beneficiaries, as well as public goods on behalf of the government, and enjoy (partial) tax-exemption. Thus, the role of intermediaries sometimes overlaps with those of providers and policy actors. NPOs additionally also employ and supply volunteer labour, a unique feature.

1.5.2

Providers

Providers in the ERI system take on two roles. First, they act as a source of DIs through the technologies developed in basic and applied research at HEIs and private research facilities. Second, schools and HEIs can equip households (and thus employees and managers of firms) with the necessary knowledge and skill set to become more adaptive and resilient in facing the potentially disruptive technologies.

Providers, who are a source of DI, do not make the innovations disruptive themselves. This depends instead on the reaction of market participants. Before households face the effects of a possible DI, the knowledge created by ERI providers is offered as a service on the product market, either at a cost or free of charge. Firms able to integrate these new technologies then commercialise this knowledge and build products or restructure the architecture of their production processes.[16] These products and technologies then act as either a demand- or supply-side disruption. When successfully established on the product market, these innovations make services and goods better or cheaper for consumers (households) but also may lead incumbent companies to fail, which ultimately also affects households, as employees lose their jobs and shareholders their money. At the same time, new market entrants gain bigger market shares and thus demand more labour and capital on the resource market. This again affects households as suppliers on the resource market. The shift in technology and market power may also lead to a shift in demanded skills and knowledge, affecting households' demand for the providers' services. In the optimal case, these shifts ultimately have net benefits for the economy and society, however, it is not guaranteed that benefits are distributed equally, and transitional phases can be stressfull.

The speed at which knowledge and technology (created by providers of the ERI system) are absorbed by firms differs and may determine whether companies or labour market participants will be disrupted by emerging technologies. Disruption may happen because transitional phases were too short and did not allow for an adaptation (building resilience), or because companies or the labour force were not willing or able to absorb the technologies. In steering the flow of knowledge and technology transfer (KTT) and determining the range of dissemination, providers of the ERI system can influence the emergence or absence of disruption.

16 Innovation processes are rarely linear. The diagram in Figure 1.4 based on these theoretical considerations should be understood as both abstract and illustrative.

KTT schemes are instruments, which are not solely applied by providers in the ERI system. They are rather a form of cooperation between the providers and private firms, intermediaries, policy actors, and households.[17] Some of the most prominent KTT initiatives situated or owned by providers of the ERI system include:

- KTT agencies and companies established or situated at HEIs;
- National Centres of Competence in Research (NCCR), situated at HEIs but funded by the Swiss National Science Foundation (SNSF, an intermediary); and
- National Thematic Networks, a collaboration between HEIs and companies, but funded by the Commission on Technology and Industry (CTI) (an intermediary). They are sometimes themselves organised as association (an NPO).

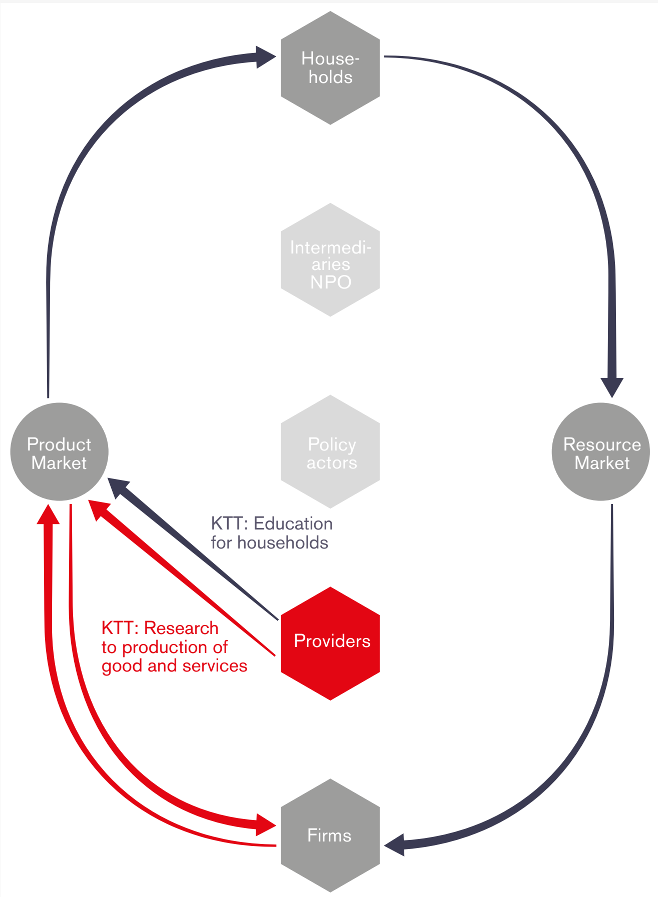

Figure 1.4. Instruments of providers in the ERI system

Acting as suppliers of education to households, the providers of the ERI system play a central role in helping them to adopt the right strategy to prevent the emergence of innovations from becoming a disruptive event. In the Swiss high-tech and high-skill economy, an "obsolescence of education" (see Neuman & Weiss, 1995) is a vital issue that needs to be addressed. An analysis based on Swiss data confirms this is a potential problem and concludes that "technological change will probably have a higher impact on earnings profiles than in natural resource-intensive economies, an impact that may be magnified in Switzerland owing to the rapid ageing of its workforce" (Ramirez, 2002, p. 9).

Switzerland's vocational education and training (VET) system plays a dual role. When looking at innovations in information and communications technology (ICT) as a potential source of disruption, VET may prevent the substitution of the labour force and keep the labour share stable:

> The VET system … seem[s] to have the effect of making newly trained apprentices used to ICT tasks, and therefore shields them from being substituted by ICT later in life. A second potential effect of the VET system relates to the idea that current apprentices are not allocated to jobs which are subject to routinization by ICT, since firms decide themselves which type of apprenticeships they offer, aligning the skills of their apprentices to the firm's production. (Siegenthaler & Stucki, 2014, p. 18)

Seufert and Vey (2016) suggest five areas in which HEIs can contribute to using the strategy of "wait and double up" and thereby prevent technologies from becoming disruptive (here: digital technologies):

- Understanding digitalisation in knowledge work as an augmentation instead of a substitution;
- Learning to make decisions together with AI, using it as a digital assistant, but also understanding its limits;
- Strengthening the human core competencies which computers will (probably) not challenge in the near future, including creativity, empathy, the use of abstract notions, and generalisation;
- Understanding differences in the communication between humans and machines;
- Incorporating the implications of digitalisation on how firms function.

17 In the context of the Triple Helix System, Ranga and Etzkowitz (2013) call these "multi-sphere" or "hybrid" institutions and they may play a central role in building a competitive advantage for a country.

One of the most important instruments of KTT for industry is the employment of graduates (see for instance Foray, 2007). ERI providers need to educate the future managers of firms in how to adopt an integrated company structure. This can allow for the absorption of new production processes. Understanding how important it is to build resilience, even in the absence of past failures and in the face of apparently sufficient current measures (cf. Vogus & Sutcliffe, 2007), is key in preparing actors in the economy to face the uncertainties that are inherent to DI. The following instruments of schools and HEI are suited for this task:

- Teaching adequate skills which can be complementary to potentially disruptive technologies;
- Teaching adequate skills to absorb and deal with new technologies in a useful way;
- Teaching adequate basic knowledge which is still relevant given the availability of new technologies.

1.5.3

Intermediaries

Intermediaries themselves do not primarily act as a source of DI.[18] However, they contribute to shaping the environment that allows for or prevents a technological innovation to become disruptive. Additionally, intermediaries voice the concerns and interests of all actors in the Swiss economy and society. Such concerns go well beyond economics, as NPOs are vital places for the reproduction of social capital (for an overview see von Schnurbein, 2014). Thus, the voicing of social and ethical concerns is a central task of these organisations. As Helbing et al. (2016) point out, sociodiversity not only fuels collective intelligence and innovation, but also resilience. Thus, NPOs may contribute to making the Swiss economy and society more resilient. Concerns about the negative effects of potential DI are better heard before they become truly disruptive. Labelling current developments as a threat may release needed funds to ERI providers to find progressive solutions, following Gilbert and Bower's (2002) proposed framing concept (see Subsection 1.3.1).

Unions and employer associations are also intermediaries. Unions call for market regulation and better education and engage in wage bargaining. Thus, they play an important role in preventing a decrease in labour share. Simultaneously, the agenda of employer associations is to seize the chance to commercialise breakthrough innovations most effectively in order to ensure economic growth and productivity increases.

Intermediaries in the ERI system further foster and finance research, predominantly through the SNSF and the CTI. Research funding from private foundations is becoming increasingly important as well (von Schnurbein & Fritz, 2014), though the amounts they spend on research are no match for what companies and government invest (SERI, 2016). However, given their freedom of action, potential to bear risk and flexibility, such private funds may speed up processes as well as create slack and thus build resilience. Intermediaries also contribute to flexibility in the economic system through financing start-up companies, thus affecting the speed of KTT. Finally, intermediaries are important players in agenda setting. Raising awareness of the necessity to teach certain skills and expand research in certain areas may increase the complementary and productive use of advanced robotics and AI.

18 As social innovators NPOs may as well develop innovations which affect other market participants. The subject of social innovations however is not considered further in this analysis.

There are manifold instruments intermediaries have at their disposal, and NPOs also enjoy a certain freedom and flexibility which firms and/or government do not have. Their most important instruments are:

- Supplying advocacy & raising awareness;
- Supplying services to members/beneficiaries & building social capital;
- (Flexible) research/start-up funding;
- Piloting of initiatives and an ability to bear risk.

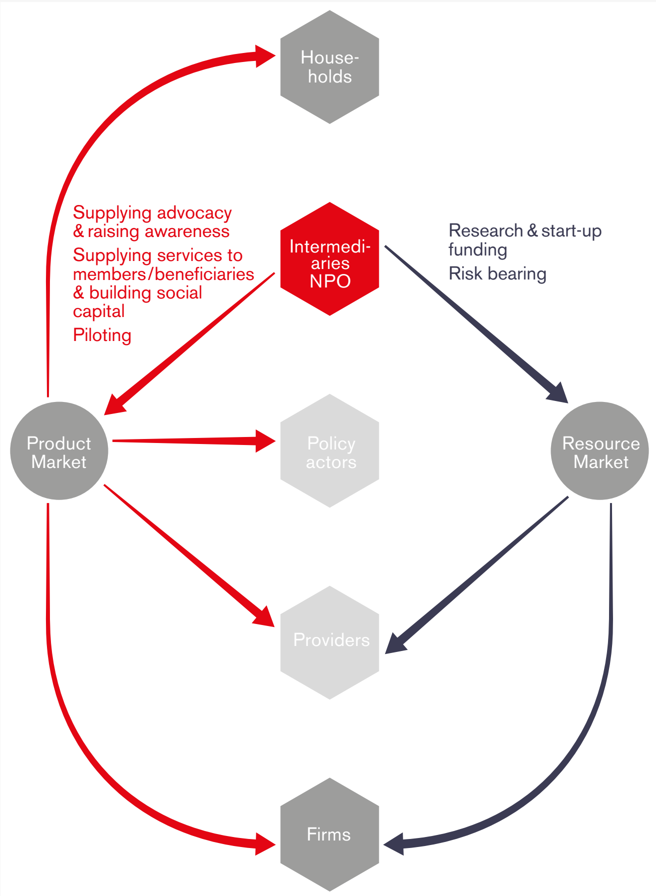

Figure 1.5. Instruments of intermediaries and NPO in the ERI system

1.5.4

Policy actors

Policy actors in the ERI system do not act as a source of DI but they shape the environment in which such technological innovations take place. Though not part of the ERI purview, it is worth pointing out that highly regulated sectors (such as finance) are better shielded from DI. In addition to legislation and public policy, "informal institutions such as the labour market, the venture capital (VC) market, and the buyer-supplier market also condition the effects of technological change within an industry" (Chesbrough, 1999, p. 323). Blind (2016) also points out the effect labour market regulations have on the emergence of specific forms of innovation. While consensus-based regulations (such as in Germany) favour incremental innovation, deregulated and liberal markets (such as in the USA and the UK) favour radical innovation. Blind (2016) further notes that changes in the regulatory environment favour the emergence of DIs.

Policy actors therefore are not only responsible for distributing funds (raised through taxes from firms and households) to providers or intermediaries in the ERI system but may also shape and regulate marketplaces in which the effects of a DI spread and affect households and firms. This includes coordinating efforts and stakeholders as well as setting priorities in initiatives. Acting as "first consumer", federal or local governments can foster innovation processes through demand-side means such as public procurement (Edquist, Vonortas, Zabala-Iturriagagoitia, & Edler, 2015).[19]

Regulating the environment in which innovation emerges is much more effective than trying to directly influence innovation itself. Still, policy especially matters "during revolutionary periods" (Foray, 2007, p. 67). In its policies, "Switzerland has traditionally and consistently been oriented to subsidiarity and self-management principles. ... Political decisions therefore focus on the (concertated) design of the framework conditions ('contexts') for supporting university instruction, research, and innovation, as well as the rules for obtaining public funding for them" (SSIC, 2015a, p. 29).

19 In 2015, Swiss public consumption was estimated to account for more than 11% of GDP (Source: Federal Statistical Office, National accounts).

Finally, there exists the issue of legal uncertainty with regard to technological innovations, including liability (Scherer, 2016) and licencing. This could hamper innovation and limit consumer adoption (Richards & Smart, 2016). Legal uncertainties also reflect a currently low level of social acceptance of certain technologies. They thus may act as natural means of prolonging transitional phases, giving households more time to adapt to new technologies, or possibly even preventing disruption. At the same time, legal uncertainties limit the pioneering effects of innovation, which is not beneficial with regard to international competitiveness. It could, in turn, lead to the disruption of Swiss firms by international competitors. In dealing with such legal uncertainties, policy actors may need to interact with providers and intermediaries in the ERI system, for instance with regard to the legal status of autonomous systems or robots.[20] Winfield and Jirotka (2017, p. 3) further note that there "is little doubt that rapidly emerging and highly disruptive technologies such as drones, driverless cars and assistive robotics require – if not new law – regulation and regulatory bodies at the very least."[21]

Instruments available to policy actors in the ERI system include:

- Legislation with regard to innovation in Switzerland, including handling certain legal uncertainties;
- Financing public education and research directly through providers or intermediaries such as the CTI and SNSF (includes KTT schemes);
- Regulation of markets (labour market, VC market, etc.) and setting framework conditions;
- Public procurement.

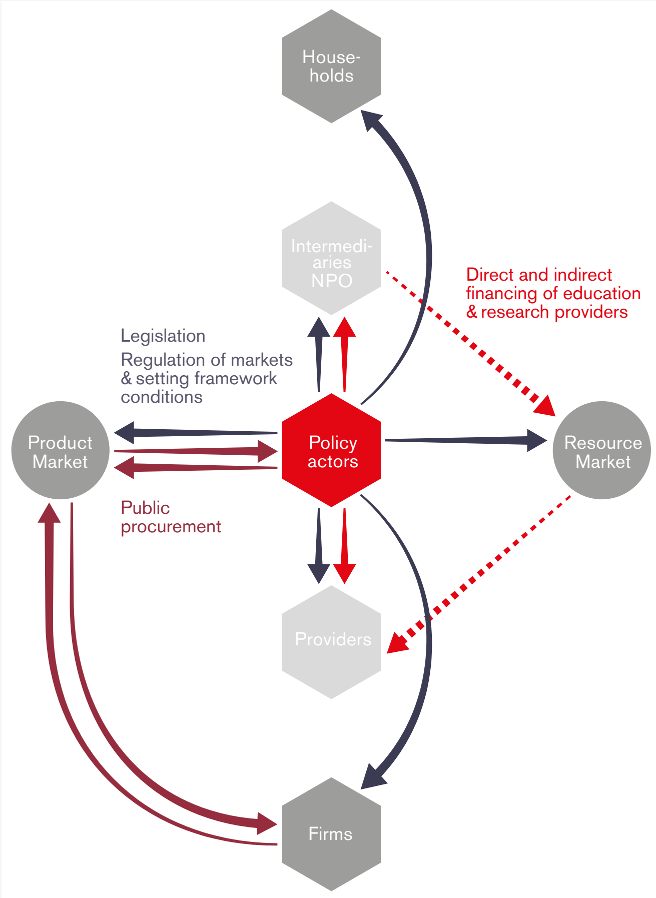

Figure 1.6. Instruments of policy actors in the ERI system

20 An extensive discussion of legal issues with regard to the sharing economy forms part of the recent publication by the Bundesrat (2017) on the framework conditions for the digital economy.

21 In the context of autonomous systems they specifically call for an "ethical black box", which should help trace the decision making process in the case of harmful errors. They state that "it should always be possible to find out why an autonomous system made a particular decision (most especially if that decision has caused harm)" (Winfield & Jirotka, 2017, p. 5).

1.6
Key issues

In its November 2016 plenary meeting, the SSIC discussed in three working groups key issues with regard to the effects of potentially disruptive technologies on the three areas of the ERI system. The following nine problems and related key issues emerged:

Education

- 1st problem: Faster cycles of technological change with regard to…
  Studying: Is there a need for adjustment in the structures/curricula of the educational system? Is there an expiration date of education/certificates (related to the problem of occupational obsolescence)? What are alternative modes of studying in terms of time models? Diplomas vs skills? / Faculty: Is the tenure system still justified? / Companies: Should firms have greater responsibility to foster the continued training of employees?

- 2nd problem: Specialised vs transdisciplinary skills
  What is the appropriate "T-shape"[22] of education for the future workforce? Which knowledge/skills should be taught in which way and what is the (potentially) new basic knowledge?

- 3rd problem: Capital-biased vs skill-biased technological change
  Which (potentially) disruptive technologies favour capital/labour, which high/low skills? How do these technological advances affect the necessary qualifications for future jobs? How does the education system need to react/adapt to these biases?

Research

- 1st problem: ICT vs other disciplines
  Will future research move further towards big data and ICT-intensive methodologies? Should research in digital technologies be fostered further? Which disciplines would be "left behind" and neglected, which ones are complementary to digital technologies and should be fostered as well?

- 2nd problem: Conservative research culture – good or bad?
  Is the conservative and consensus-based research and HEI culture beneficial for the Swiss landscape in coping with disruptive technologies? Does research and its funding organisations need to become more open to explore the potential DI and willing to take more risks?

- 3rd problem: (Flexible) Research funding in an uncertain context
  Innovative/disruptive technologies cannot be funded directly, as there is too much uncertainty involved in how these will develop. Which forms of financing complement current "conservative" instruments?

Innovation

- 1st problem: Social and ethical implications of disruptive innovations
  DIs do not only have economic implications but also social ones. What else needs to be considered (marketisation/economisation, inequality, human "disenhancement", etc.)? Where are risks? Which ethical implications do these potentially problematic social impacts have on innovation funding?

- 2nd problem: Positive and supportive framework conditions
  How can (regulatory) frameworks prevent inefficiencies, redundancy, and monopolies, while promoting diversity?

- 3rd problem: Agility of small and medium-sized enterprises (SMEs)
  What else needs to be done in order for SMEs to find their niches in future, potentially disruptive markets and retain their competitiveness? Which knowledge and technology transfer schemes (KTT) would work best in disruptive environments?

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22 "T-shape" is a metaphor for the degree of a person's skill specialisation (vertical bar) and ability of cross-disciplinary collaboration (horizontal bar) and is mainly used in recruiting. David Guest first referenced it in an article in The Independent in 1991, however, Tim Brown from IDEO, a design consultancy, used the term most prominently.

1.7 Conclusion

DI is a paradoxical phenomenon: Well-managed companies fail because they keep doing what made them successful, including continuously investing in innovative technologies. At the same time, DI introduces products to the market that are easier to use and cheaper, increasing customers' utility. Thus, the effects of DI go beyond a single company's or industry's scope. DIs also affect consumers, the labour force, and maybe even an entire economy or society.

Managerial literature suggests several strategies to deal with both demand- and supply-side DI such as building resilience, self-disruption, and a more integrated company structure. In supplying education, the ERI system plays a central role in making future management and the work force more resilient and adaptive to change. The ERI system further can help firms to efficiently exploit the merits of automation through investing in research and providing frictionless KTT platforms as well as means for commercialisation. Intermediaries of the ERI system, such as NPOs with their freedom of action (derived from their legal status), may provide flexible solutions in the context of uncertainty inherent in DIs. They also can be important in framing automation as a potential threat in order for policy actors to release enough resources for the providers in the ERI system to create progressive and constructive solutions. Additionally, policy actors are central in shaping the framework conditions for a more productive exploitation of potentially disruptive technologies without stressful transitional phases for economy and society.

The SSIC has discussed several key issues concerning the Swiss ERI system and potential DIs, and identified nine central problems. Among other things, these involve the fostering of skills and competencies which are complementary to the potentially disruptive technologies, the role of KTT schemes, the agility of SMEs in dealing with DI, the social and ethical implications of such innovations, and whether increasingly fostering ICT comes at the cost of neglecting other disciplines.

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Digitalisation

Exploratory study written by the Swiss Science and Innovation Council SSIC

2

2.1 Introduction

In its November 2016 plenary meeting, the Swiss Science and Innovation Council (SSIC) invited Vivek Wadhwa, professor at Carnegie Mellon University's College of Engineering, to give a keynote speech about the future of technology and its potentially disruptive effects. This invitation was part of the SSIC's efforts in engaging with one of the overarching themes in its 2016–2019 Working Programme titled "disruptive change in economy and society by technology and other drivers". Prof. Wadhwa proceded to present different technological developments in the field of genome sequencing, personalised medicine, bionics, robotics, artificial intelligence (AI) and machine learning (ML), additive manufacturing, drones, and energy storage which might disrupt entire sectors and industries. He concluded that it is up to entrepreneurs to use these accelerating technological developments to make "magic happen" – while at the same time pointing out that much of the technological achievements today are not used to address society's grand challenges as "we are out of touch with the needs of the world." [23]

Out of the many aforementioned technological innovations, the general process of digitalisation, including advanced robotics, AI, and ML has especially been of interest to the Swiss political system (Bundesrat, 2017; SBFI, 2017). If appropriate skills, competences, and infrastructure are not going to be available, businesses and the labour force might be negatively affected by the current development, including a potential widening of the gender and socioeconomic gap in Swiss society. Advanced robotics, AI, and ML are encroaching fields, in which humans have been incumbent suppliers for centuries: routine and non-routine labour tasks. The discussion about how machines are putting jobs at risk and are causing technological unemployment is not new at all. Neoclassical economists refer to this anxiety as the Luddite fallacy. Neoclassical theory thus predicts that although technological advancements may temporarily displace jobs, they create more than they destroy, a principle that is also known as creative destruction.[24]

23 A complete transcript of his presentation can be found in the Appendix of this paper on page 52.

24 This has been famously discussed by Schumpeter (1942).

Current developments in job automation, however, have caused an "automation angst"[25] and lead scholars (among them Stephen Hawking and Paul Krugman) to express words of warning or worry, even though there is no evidence of long-term technological unemployment from past technological revolutions. Smart algorithms and tactile robots may put up to 50% of current jobs at high risk of substitution (Frey & Osborne, 2013), which also applies to the Swiss economy according to the estimates of Brandes and Zobrist (2015). Although such prognoses may underestimate the aspect of complementary effects (Autor, 2015) or are biased because of the definition of job routines (Arntz, Gregory, & Zierahn, 2016), the issue of job automation should still be treated seriously.

The case of digitalisation as a part of the SSIC's exploratory efforts lends itself for two reasons: First, it is of high relevance to the Swiss economy, characterised by its high level of technological development and lack of natural resources. Second, as not only firms are affected by job automation but mainly also the labour force, the case is of direct relevance to the Swiss education, research, and innovation (ERI) system, thus the primary focus and field of expertise of the SSIC.

This paper closes with an exploratory mapping of current efforts and initiatives in Switzerland in the context of digitalisation and its underlying, potentially disruptive technologies. This overview covers all three types of actors present in the ERI system: providers (such as higher education institutions [HEI], etc.), intermediaries (such as the Swiss National Science Foundation [SNSF] and non-profit organisations [NPO]), and finally policy actors.

25 The term was used in an article of the same title in The Economist ("Automation angst", 2015).

2.2 Prognoses and economic theory

In the course of digitalisation, ever-increasing computing capacities and smart algorithms may lead to the automation of a significant fraction of the jobs in developed economies. Arthur (2011) describes the current developments as the formation of a neural system inside the economy, in contrast to building a muscular system during the Industrial Revolution. While past technological revolutions have introduced substitutes for muscular power, the current developments introduce ways machines can provide autonomous, intelligent responses without the involvement of humans. He predicts future long-term economic growth and increasing wealth. However, "there may be prosperity without full access for many" (Arthur, 2011, p. 97). Information technology (IT) expert Martin Ford and Massachusetts Institute of Technology (MIT) scholars Erik Brynjolfsson and Andrew McAfee predict a new form of industrial revolution, in which robots and smart algorithms will replace human labour. Their prognoses have much in common with past dystopian visions of how technological innovation will wipe out labour across the economy and cause technological unemployment (as argued by Keynes, 1963).

However, their argument differs. This type of technological change may not only be skill-biased but rather capital-biased (for a historical discussion see Goldin & Katz, 2008) and thus will not necessarily be overcome by better education (as Keynes argued). Digitalisation enables winner-take-most markets to develop and through the ability to replicate at nearly zero cost, this revolution differs greatly from past ones. Brynjolfsson summarises the possible danger as follows: "technology progress does grow the economy and create wealth, but there is no economic law that says everyone will benefit" (in Rotman, 2013, para. 35). Krugman (2012, para. 8) supports this notion by pointing out that "better education won't do much to reduce inequality if the big rewards simply go to those with the most assets." Arthur (2011), Ford (2015), and Brynjolfsson and McAfee (2014) call for a guaranteed basic income and other means of redistribution to mitigate the possible disastrous effects on the economy, including a collapse of demand by households and an increasingly unequal wealth distribution. Krugman (2013, para. 12) also calls for "a strong social safety net, one that guarantees not just health care but a minimum income, too." This safety net, Krugman (2013, para. 12) continues, "would have to be paid for to an important extent via taxes on profits and/or investment income." A global intervention would be necessary, in the view of Loi (2015),[26] to mitigate the negative effects and threat of "human disenhancement" through automation. Yet this is neither realistic nor feasible within a useful time frame.

26 Loi (2015, p. 209) further introduces more radical ideas, such as "the introduction of genetic, pharmacological or public health approaches to intelligence enhancement … . In other words, biomedical enhancement may become a necessity to merely counterbalance human disenhancement due to increased competition with machine intelligence."

He therefore calls for public policies that can influence the wider environment, such as fostering education that augments human skills through robotics and AI. This may require investing more in early education.

Ford (2015) and Brynjolfsson and McAfee (2014) draw attention to several economic phenomena in the USA that show how computer-based automation is already encroaching on human labour. They see a decoupling of productivity from wages, which historically have moved in parallel, and call the phenomenon "the Great Decoupling". However, the phenomenon of "the Great Decoupling" has been challenged by Boudreaux and Palagashvili (2014) on the basis of the inaccurate measures used. The digitalisation of the economy has an impact on the accuracy of measuring wealth: Freely available services, entertainment, and upgrades increase life quality, but are not included in gross domestic product (GDP) because these services lack prices (see The Economist "Measuring economics: The trouble with GDP", 2016; Nolan, Roser, & Thewissen, 2016).[27] But, additionally, Brynjolfsson and McAfee (2014) point out that the labour share of GDP and the median income have been dropping and there is an ongoing polarisation of jobs based on the skill levels required.

A decrease in the labour share of GDP is highly problematic, as it threatens social cohesion. Job polarisation means middle class jobs are most prone to automation, as they consist of easily replicable routines. Low-skill jobs often involve manual labour, much of which remains, for now, too complex for robots. This is Polanyi's paradox: Humans can complete several tasks effortlessly without being able to describe how the mechanisms work: "We know more than we can tell." Autor (2015) maps out two ways of overcoming this limitation: environmental control and machine learning. "The first path circumvents Polanyi's paradox by regularizing the environment so that comparatively inflexible machines can function semi-autonomously. The second approach inverts Polanyi's paradox: rather than teach machines rules that we do not understand, engineers develop machines that attempt to infer tacit rules from context, abundant data, and applied statistics" (Autor, 2015, p. 23).

However, it remains unclear what genuinely contributes to the phenomena of the decreasing labour share and job polarisation. At least Autor, Levy, and Murnane (2003) find evidence that tasks most readily computerised have led to a shift in the demand for educated labour. Next to shifts between different levels of job skills, Cain Miller (2017) discusses whether digitalisation also could have gender-specific effects. "Pink-collar jobs" (such as health care aides), which are largely held by women, may see high growth rates in the future. At the same time, the jobs most likely to decline in the USA are male dominated and blue-collar (such as vehicle electronics installers). Additionally, a 2014 survey among eighth-grade students has also shown that girls display higher digital competences than boys across all surveyed OECD countries (Bos et al., 2014).

A study by Frey and Osborne (2013) estimates that almost 50% of the current jobs in the USA are at high risk of being eliminated through automation during the next decades. A similar study from the OECD (Arntz et al., 2016), covering 21 nations, predicts a much lower percentage of jobs at high risk, ranging from 6% (South Korea) to 12% (Austria and Germany). Still, they state that "the development of digit[al]ised economies is likely associated with large shifts between occupations and industries, forcing workers to adjust to the changing economic environment" (Arntz et al., 2016, p. 24). The main reason for these big variations in estimates is the differentiation between "jobs" and "tasks".

Autor (2015, p. 22) elaborates: "jobs are made up of many tasks and that while automation and computerization can substitute for some of them, understanding the interaction between technology and employment requires thinking about more than just substitution." Thus, Autor (2015, p. 27) does not share the view, that job polarisation will continue and "middle-class workers are doomed by automation and technology." He stresses that "human capital investment must be at the heart of any long-term strategy for producing skills that are complemented by rather than substituted for by technological change." He argues that automation does not only substitute for labour but also complements it.

Graetz and Michaels (2015) find that industrial robots increase wages and productivity but do not significantly affect total hours worked. However, using robots does seem to result in a reduction of the working hours of low- and middle-skilled workers. Thus, automation is only a danger when the labour force is not equipped with the skills that complement the evolving technologies. Only when machines and algorithms are able to complete non-routine tasks, this argument goes, will automation become a true threat. ML may be a way of achieving this, but it is, for now, not at the level of human abilities. If human labour at some point will indeed become obsolete, "then our chief economic problem will be one of distribution, not scarcity" (Autor, 2015, p. 28). He thus addresses the paradox of abundance: Households earn wages as a compensation for labour, as it is a scarce resource. Usually abundance of a resource is desirable, but if labour becomes abundant, wealth redistribution might be necessary in order to keep the economic cycle running: An abundance of labour means households lose their primary source of income.

27 For an extended discussion of GDP and alternative measures, see Stiglitz, Sen, and Fitoussi (2010).

Mokyr, Vickers, and Ziebarth (2015, p. 47) also argue that long-term and ineradicable technological unemployment is highly unlikely, though the "transition to this economy of the future may be disruptively painful for some workers and industries" and "will require public policy to ameliorate the harshest effects of dislocation." This may include forms of income or wealth redistribution or public goods such as education. Furman (2016, p. 14) similarly argues that public policy "has a role to play in ensuring that we are able to fully reap the benefits of AI while also minimizing its potentially disruptive effects on the economy and society. And in the process, such policies could also contribute to increased productivity growth – including advances in AI itself."

A recent report from the World Economic Forum on the future of jobs estimates that 65% of children entering school today "will ultimately end up working in completely new job types that don't yet exist. In such a rapidly evolving employment landscape, the ability to anticipate and prepare for future skills requirements, job content and the aggregate effect on employment is increasingly critical for businesses, governments and individuals in order to fully seize the opportunities presented by these trends – and to mitigate undesirable outcomes" (World Economic Forum, 2016, p. 3).

2.3 The Swiss case[28]

2.3.1 Assessment

How do these prognoses of the risk of automation apply to Switzerland? While Frey and Osborne (2013) and Arntz et al. (2016) do not include data on Switzerland, Brandes and Zobrist (2015) replicated the Frey and Osborne (2013) study and found nearly 50% of current jobs were at high risk of being substituted in Switzerland. The probability of automation correlates negatively with the skill level required. The Jobs which are most prone to automation are in administrative and secretarial occupations, while managers, directors, and senior officials face the lowest risk. An overview of the estimated risk by industrial sector can be found in Table 2.1.

Sector	% of jobs at high risk	No. of jobs at high risk
Agriculture & forestry	76%	74,000
Property & rental sector	60%	n.a.
Construction	51%	138,000
Wholesale and retail trade, transportation and storage	49%	434,000
Manufacturing	47%	267,000
Freelance, academic and technical services	32%	156,000
Financial and insurance services	29%	67,000
Other services	22%	37,000
Information and communication	19%	24,000
Public administration, health and social services	17%	133,000

Table 2.1. Probability of automation by industrial sector, sorted by percentage of jobs at high risk

28 For an extensive analysis see also the audit report by SBFI (2017).

Based on the different methodologies (jobs vs tasks), there is substantial disagreement about the possible effects of the development of automation. However, even the lowest estimate (Arntz et al., 2016) suggests 6% of current jobs are at high risk of becoming automated. Losing these jobs would increase the current Swiss unemployment rate[29] to about 9%. Although this rate is still low in comparison to other European countries, this implies an increase by 200%. However, the Swiss case differs in some crucial ways. Neither have the labour share of GDP and median income seen a decrease in recent decades, nor is there an ongoing polarisation of jobs based on skill level required.

Siegenthaler and Stucki (2014) note that labour shares in Switzerland have remained constant since 1980 and suggest this is due to:

- A sectoral shift towards skill-intensive industries with high labour shares (electrical & watchmaking industries; business services such as accounting or consultancy, and research & development);
- Enduring shortages of labour, limiting wage bargaining;
- A comparatively slow adoption of information and computer technology (ICT) during the 1980s and early 1990s;
- Comparatively high human capital in Swiss households, especially due to Switzerland's vocational education and training (VET) system.

With regard to job polarisation, Murphy and Oesch (2016) find that over the past four decades, the majority of jobs have been created in high-level, and the fewest in low-level occupations. The Swiss job market has mostly seen upgrading and upskilling, with migration policies a major reason for the absence of polarisation in the last decade. Unlike in the 1980s, the policy introduced in the 2000s targeted high-skilled immigrants. Murphy and Oesch (2016) list additional factors ranging from labour market institutions to the educational system, which together explain how developments in ICT have not had the same effects on the Swiss economy as in other countries. This could explain why the Swiss labour share has not decreased, as more highly skilled workers typically have a higher labour share than do less-skilled workers (see ILO & OECD, 2015).

While it remains unclear how the Swiss workforce will ultimately be affected by digitalisation and the potential of automation, the threat it poses should be taken seriously. However, digitalisation also offers opportunities for the Swiss economy and society, and (as Autor, 2015 also argues), examining this development from a complementary instead of a substitution point of view might offer a solution for the stagnating productivity of the Swiss economy. Augmenting labour with the help of advanced robotics and AI may increase labour productivity and lead to economic growth.

A recently published report on the "New Growth Policy" by the Federal Department of Economic Affairs, Education and Research identified several sectors which have contributed most to the slowing down of productivity growth,[30] particularly the financial sector, but more recently, the industrial and trade sector as well. In addition, administrative burdens and the scarcity of experts are cited as reasons for this slowdown. In all these fields, advanced robotics (industry, trade) or AI and ML (trade, financial sector, and administrative tasks) could boost productivity. Therefore, the potential threats automation poses could be an opportunity for Swiss firms to achieve the goals of the "New Growth Policy".

In its strategy document "Digitale Schweiz", the Swiss Confederation highlights opportunities and risks in handling digital data and guaranteeing its secure and productive use.[31] The document also discusses the implications of digitalisation for the economy. While mainly highlighting opportunities, the report also states that "Die Auswirkungen der Digitalisierung und Automatisierung auf einzelne Branchen sind zu beobachten, zu analysieren sowie allfälliger Handlungsbedarf für den Staat zu evaluieren. Dabei sollten insbesondere wettbewerbspolitische Fragen, Regulierungsfragen sowie die Auswirkungen auf den Arbeitsmarkt beachtet werden."[32]

A recent survey conducted by the Swiss Economic Institute KOF among 157 Swiss economists found about one-third predicting a long-term increase in unemployment in industrial countries, and only one-sixth predicting a decrease (Abberger & Iselin, 2016). A substantial majority (72%) were of the opinion that digital technologies will lead to an increase in income inequality. For Switzerland, however, most survey participants predicted that its economy will grow more strongly than the average industrial country due to digitalisation and robotics.

29 At the time of this paper's editing, the latest available number on Swiss unemployment was 3.0% (as of June 2017; source: State Secretariat for Economic Affairs, SECO).

30 Not available in English, see WBF (2015).

31 Not available in English, see Bundesamt für Kommunikation (2016).

32 "One can observe the effects of digitalisation and automation in specific branches. These should be analyzed and evaluated with respect to the need for action on the part of the government. Special attention should be paid to questions of competition policy, the need for regulation, and the effects on the labour market."

They also predicted an increasing demand for highly skilled workers, and a decline in the demand for those with lower skill levels. Finally, they called for a review of the framework conditions in order to make Switzerland more attractive, though the study leaves open what these conditions should be.

In a second KOF study, Arvanitis, Grote, Spescha, Wäfler, and Wörter (2017) surveyd 1,183 companies with a focus on the effects of digitalisation. 76% of the responding businesses report no changes in overall employment numbers between 2013 and 2015, 12% a decrease, and 11% an increase. Digitalisation seems to have an effect on the composition of staff according to their level of qualification. The study's authors report that "companies recorded an increase in graduates from universities of applied sciences/technical colleges and candidates with vocational qualifications. A slightly lower net rise was reported with regard to university graduates. In contrast, the trend among semi-skilled/unskilled workers appears to be negative. These developments are particularly present in large companies, while increased demand for individuals with vocational qualifications is more prevalent among smaller companies."[33] There are also differences in the perception of the effects of digitalisation on the companies' competitiveness: While 30% of small companies see digitalisation as having positive effects on their competitiveness, that number increases to 49% for big companies.

2.3.2
Current efforts and initiatives[34]

What follows is an overview (not exhaustive) of efforts currently being undertaken by ERI actors which are related to technological developments in the area of digitalisation. This overview is based on desktop research using keywords closely related to digitalisation and automation.[35] Grass and Weber (2016) also provide an excellent survey of European efforts and initiatives, and a selective overview of those efforts, with additional sources for Germany, can be found in the Appendix on page 50.

Providers

Those who educate and conduct research at the tertiary level play a key role in the ERI system, and Swiss HEIs contribute to knowledge of technology and automation at, among others:

- The Swiss AI Lab IDSIA at the Università della Svizzera Italiana (USI) and University of Applied Sciences and Arts of Southern Switzerland (SUPSI);
- The Conscious Analytics System Laboratory at the University of Geneva;
- The UZH Digital Society Initiative at the University of Zurich;
- The Professorship of Computational Social Sciences at the ETH Zurich;
- The Swiss Competence Centre for Innovations in Learning at the University of St. Gallen;
- The ICT-Accessibility Lab at the ZHAW School of Engineering.

For the knowledge and technologies created at HEIs to have an impact on actors in the Swiss economic and social system, knowledge and technology transfer (KTT) schemes are vital. Organisations which link HEIs with businesses in Switzerland include:

- The Geneva Creativity Centre in cooperation with the University of Geneva and University of Applied Sciences and Arts of Geneva;
- The Swisscom Digital Lab at the EPF Lausanne;
- The National Center of Competence in Research (NCCR) Digital Fabrication at the ETH Zurich.

One of the most important aspects of KTT is education and the employment of graduates. Swiss ERI providers offer numerous specialised courses covering diverse aspects of digital technologies which influence automation. A few examples are:

- The Master of Advanced Studies (MAS) course in Digital Business at the HSW University of Applied Sciences in Business Administration Zurich;
- The seminar on Digital Leadership at the University of Applied Sciences and Arts Northwestern Switzerland;

33 See press release in English: https://www.kof.ethz.ch/en/news-and-events/media/press-releases/2017/06/digitalisation-has-little-effect-on-employment.html. The complete study is only available in German (Arvanitis et al., 2017).

34 See the Appendix for weblinks to the initiatives and organisations noted in this section.

35 The following terms (and their respective German, French, and Italian translations) were used: digitalisation, digital transformation, automation, artificial intelligence, robotics, digital economy, digital competences.

- The lecture course on "Digital Transformation – Why and how firms must adapt the way they do business" offered by the Chair for Marketing and Market Research at the University of Zurich;
- The Master Research Unit (MRU) on Intelligent Systems at IDSIA (USI/SUPSI);
- The Certificate of Advanced Studies in Digital Transformation at the Lucerne University of Applied Sciences and Arts.

Intermediaries

Intermediaries and NPOs enjoy a certain freedom of action, given the Swiss legal framework. Like the activities of policy actors, intermediaries provide advocacy as a service to their members, who may include researchers, unions, or industry actors. Intermediaries provide public services to members and beneficiaries and often represent a form of cooperation between public and private or non-profit actors. Examples include:

- digitalswitzerland (a cross-industry association);
- e-inclusion (a network of public authorities, interest groups, and businesses);
- eGov-Schweiz (an association of public, private, and HEI representatives, which promotes e-governance in Switzerland);
- Industry 2025 (an initiative of four industrial associations);
- The Swiss Association for Computer Science in Education (an association of teachers, education institution, NPOs, and private companies);
- swiTT (an association of technology transfer professionals).

The academies, including the Centre for Technology Assessment (TA-SWISS, organised as a private foundation) are also intermediaries in the ERI system. TA-SWISS recommendations are used by political decision-makers, as well as the media and citizens, in identifying the (potential) consequences of new technologies.

Finally, private foundations and public funding agencies (SNSF; Commission for Technology and Innovation) play a key role in the ERI system in distributing funds and bearing risks. Private foundations include:

- The Hasler Foundation (promotes education, research and innovation in ICT, for instance with its PrimaLogo programme);
- The Dalle Molle Foundation (supports general interest, innovative and high-quality scientific projects – including the IDSIA at the USI/SUPSI);
- The "Im Grüene" Foundation (operates the Gottlieb Duttweiler Institute, a think tank which provides many reports about digital transformation);
- The Fondation CH 2048 (one of its major foci is the digital revolution);
- The Zukunftsfonds Schweiz (a foundation which promotes the idea of using pension funds to increasingly invest in start-up companies);
- Venture Kick (a private consortium of foundations, companies, and individuals investing in start-up companies).

Policy actors

Policy actors directly and indirectly fund a diverse array of educational and research institutions in Switzerland, it is, however, beyond the scope of this paper to provide a comprehensive overview of the impact of that money on the emergence of disruptive technologies and how it helps the Swiss economy and society to build resilience.

However, strategic documents, reports, and initiatives help understand the current efforts made by Swiss policy actors in dealing with potential DIs.

- The strategy document "Digitale Schweiz" (Bundesamt für Kommunikation, 2016) only mentions potential economic disruption in passing.
- The current ERI Dispatch identified "Industrie 4.0" as a key issue, but did not mention either AI or ML.
- End of 2016 a coordinating committee on digitalisation in education (KoA Digi) has been mandated and will be coordinated by the State Secretariat for Education, Research and Innovation.
- The Federal Council recently published a report on the framework conditions of the digital economy (Bundesrat, 2017), and it includes an analysis of the role of research and education in the future development of such an economy. The Federal Council notes two specific areas for future action: "Challenges to the education system" and "challenges for research and development at Universities". These include the role of VET and higher education in training people for future employment, potential research gaps with regard to the digital transformation, and capacities to ensure knowledge and technology transfer (KTT).

Following the Federal Council's initial report, the State Secretariat for Education, Research and Innovation (SERI) published its first audit report "Herausforderungen der Digitalisierung für Bildung und Forschung in der Schweiz" in July 2017 (SBFI, 2017). In the report, technologies driving digitalisation are considered new basic technologies. Although Switzerland has well-functioning infrastructure and institutions, the SERI identifies several gaps with regard to Switzerland's ability to optimally deal with the challenges digitalisation poses. The report concludes with eight fields of action concerning the Swiss ERI system:

1. Improvement of digital skills in school ("Verbesserung der digitalen Kompetenzen in der Schule");
2. Usage of ICT in teaching and learning ("Nutzung der IKT beim Lehren und Lernen");
3. Swift adjustment of the education system to market requirements ("Rasche Anpassung des Bildungssystems an die Anforderungen des Marktes");
4. Coordination and communication in education cooperation ("Koordination und Kommunikation in der Bildungszusammenarbeit");
5. Strenghtening the skills of young graduates ("Stärkung der Nachwuchsqualifikation ['digital skills']");
6. Assuring interdisciplinary research regarding the effects of digital transformation on the Swiss economy and society ("Sicherung der interdisziplinären Forschung zu den Konsequenzen des digitalen Wandels für Wirtschaft und Gesellschaft in der Schweiz");
7. Strengthening the skills in basic research ("Stärkung von Kompetenzen in der Grundlagenforschung");
8. Innovation promotion: Accelerating knowledge transfer ("Innovationsförderung: Beschleunigung des Wissenstransfers").

Mapping

	Instrument	**Target groups**	**Examples**
Providers	Creation of knowledge & technologies through research	– Science itself – (Indirectly KTT instruments)	– Swiss AI Lab IDSIA at the Università della Svizzera Italiana (USI) – Conscious Analytics System Laboratory at the Univeristy of Geneva – UZH Digital Society Initiative at the University of Zurich – Professorship of Computation Social Sciences at the ETH Zurich – Swiss Competence Centre for Innovations in Learning at the University of St. Gallen – ICT-Accessibility Lab at the ZHAW School of Engineering
	KTT	– Firms (and their clients)	– Geneva Creativity Center in cooperation with the University of Geneva and University of Applied Sciences and Arts of Geneva – Swisscom Digital Lab at the EPF Lausanne – NCCR Digital Fabrication at the ETH Zurich
	Education (as special form of KTT)	– Future scientists, managers & employees – (Indirectly firms)	– MAS course in Digital Business at the Hochschule für Wirtschaft Zürich – Seminar on Digital Leadership at the University of Applied Sciences and Arts Northwestern Switzerland – Lecture on Digital Transformation at the University of Zurich – Master Research Unit on Intelligent Systems at IDSIA at the USI – CAS on Digital Transformation at the Lucerne University of Applied Sciences and Arts

Intermediaries NPO	Supplying goods & services to members & beneficiaries (advocacy, raising awareness, building social capital, social services, etc.)	– Higher education institutions (as members) – Firms (as members) – Government (as member and client) – Households (as members and beneficiaries)	– digitalswitzerland (a cross industry association) – Network e-inclusion (network of public authorities, interest groups, and businesses) – Association eGov-Schweiz (public, private, and HEI representatives promoting e-governance in Switzerland) – Initiative Industry 2025 (an initiative of four industrial associations) – Swiss Association for Computer Science in Education (an association of teachers, education institution, NPOs, and private companies) – swiTT (association of technology transfer professionals) – Stiftung im Grüene (operates the Gottlieb Duttweiler Institute, a think tank that reports a lot on digital transformation) – Fondation CH 2048 (with one of its major focuses on the digital revolution)
	Research & start-up financing (risk bearing)	– Higher education institutions (as providers) – Firms	– SNSF & CTI – Halser Stiftung (promotes education, research and innovation in the field of information and communications) – the Fondation Dalle Molle (supports general interest, innovative and high quality scientific projects, for instance the IDSIA at the USI) – Zukunftsfonds Schweiz (a foundation which promotes the idea of pension funds to increasingly invest in start-up companies) – Venture Kick (a private consortium of foundations, companies, and individuals investing in start-up companies)
	Piloting	– Households (as beneficiaries) – (Indirectly government)	– Halser Stiftung (Primalogo programme)
Policy actors	Legislation & market regulation	– Framework conditions & markets – Households – Firms – Providers	– Report on Framework Conditions for the Digital Economy – Strategy Document “Digitale Schweiz” – ERI Dispatch
	Financing research & education	– Higher education institutions – (Indirectly households)	– Annual budgets for SNSF, CTI, ETH Zurich & ETH Lausanne, etc. – ERI Dispatch
	Public procurement	– Firms	– No specific examples

Figure 2.1. Exploratory mapping of current efforts and initiatives in Switzerland in the context of digitalisation

2.4 Conclusion

Recent developments in advanced robotics, artificial intelligence, and machine learning have sparked a wave of anxiety based on the perceived threats they pose to jobs thus far performed by humans. Prognoses of the impact these technological developments might have varied greatly. However, there does seem to be agreement that, where possible, public policy should mitigate the negative effects of job displacement and potential increases in inequality of wealth distribution that could result. This is especially important as wealth distribution affects social cohesion. Although Switzerland has had a steady labour share of GDP and no polarisation in job creation based on skill levels, the threats automation poses should still be taken seriously. Simultaneously, these developments provide an opportunity: Technological innovations may offer a solution to Switzerland's sluggish productivity growth.

Thus, whether the effects of digitalisation and its underlying technological advances are going to be truly disruptive for Swiss businesses and the labour force, is highly uncertain and can only be determined in hindsight. However, this does not mean that one should wait and see, but rather develop resilience in order to effectively deal with these uncertainties. This does not only concern citizens and businesses as potential victims of disruption, but also government and policy makers, as true effects of disruption not only depend on individual and firm-level responses but also (changes in the) national framework conditions (Blind, 2016; Chesbrough, 1999).

Efforts already underway by Swiss ERI actors are diverse, as the above lists illustrate. Many of these efforts seem well suited to support the creation of resilience in companies and private individuals. However, a certain degree of uncertainty remains per definition and policy-makers and all ERI actors should try to prepare for such uncertainties. Potential threats from DI should always be taken seriously. The simple absence of failure in the past should not be interpreted as the absence of hazards or the effectiveness of current measures (Vogus & Sutcliffe, 2007). Potential threats should be faced in an open-minded and constructive way in order to guarantee that the economy and society can profit from the positive, value adding contribution of technological innovation, while mitigating its potentially stressful transition phases. Following the argument of Autor (2015), this means that we should focus on the complementary aspects of digitalisation and make sure that individuals and society have an active role in using and shaping technology in ways that augment human abilities.

When considering (semi-) autonomous technologies which partially drive the current trend of digitalisation it is important to keep in mind that such innovations do not simply emerge by themselves. They are the result of research and development activities carried out by humans in private firms (incumbent and start-ups) as well as higher education institutions. It is therefore in today's society's hands (and thus responsibility) to guarantee that these technologies are used in a way that benefits all. In their "digital manifesto" Helbing et al. (2016) stress that the prerequisite for such a thriving modern society is sociodiversity, as it not only fuels collective intelligence and innovation, but also resilience.

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Appendix 1: List of links

Providers

- Swiss AI Lab IDSIA: http://www.idsia.ch/
- Conscious Analytics Systems Laboratory: http://caslab.unige.ch/
- Professorship of Computational Social Sciences: http://www.coss.ethz.ch/
- Swiss Competence Centre for Innovations in Learning: http://www.scil.unisg.ch/
- ICT Accessibility Lab: http://accessibility.zhaw.ch/
- Geneva Creativity Centre: http://www.creativitycenter.ch/
- Swisscom Digital Lab: https://www.swisscom.ch/de/business/enterprise/angebot/geschaeftsprozesse-optimieren/digital-lab.html
- NCCR Digital Fabrication: http://www.dfab.ch/de/
- MAS in Digital Business: https://fh-hwz.ch/produkt/mas-digital-business/
- Seminar Digital Leadership: http://www.fhnw.ch/wirtschaft/weiterbildung/seminar-digital-leadership
- Lecture Digital Transformation: https://studentservices.uzh.ch/uzh/anonym/vvz/index.html#/details/2016/004/SM/50842900
- MRU Intelligent Systems: http://www.idsia.ch/idsia_en/education/master-in-Engineering/MRU.html
- CAS Digital Transformation: https://www.hslu.ch/de-ch/informatik/weiterbildung/digital-value-creation/cas-digital-transformation/

Intermediaries

- digitalswitzerland: http://digitalswitzerland.com/
- Network e-inclusion: http://www.einclusion.ch/de/e-inclusion-ch.html
- Association eGov-Schweiz: https://www.egov-schweiz.ch/de/Willkommen
- Initiative Industry 2025: http://www.industrie2025.ch/
- Swiss Association for Computer Science in Education: http://svia-ssie-ssii.ch/de/
- swiTT: http://www.switt.ch/adminall2/index.php
- TA-Swiss: https://www.ta-swiss.ch/
- Hasler Foundation: https://www.haslerstiftung.ch/index.php/en/
- Dalle Molle Foundation: http://www.dallemolle.ch/en/
- "Im Grüene" Foundation: http://www.gdi.ch/de/ueber-uns/traegerschaft
- Fondation CH 2048: https://www.ch2048.ch/
- Zukunftsfonds Schweiz: http://www.zukunftsfondsschweiz.ch/d/
- Venture Kick: http://www.venturekick.ch/

Appendix 2: Overview of European efforts

Finland

- Curriculum to introduce ICT as a core competence (including programming in 1st grade).
- Initiatives to increase cooperation between educational institutions and the gaming industry.
- National agency for technology and innovation funds ICT postdocs for working in SMEs.
- "Vigo Accelerators" (independent companies) bridge the gap in ICT start-up financing and "Tekes" (Finish Funding Agency for Innovation) invests in companies/projects which use digitalisation to create new business opportunities.

France

- Several forms of personal accounts: "compte personnel d'activité", personal education account, and accounts for preventing job risk. Employees acquire points through work and risk-exposure. The points can be invested in further education, bridging transitional phases, or to pay for early retirement.
- Programming in primary school, introduction of "enseignement d'exploration d'informatique et de création numérique" or "science of digitalization" into the curricula of schools.
- Delegation for the usage of the internet (DUI) promotes digital alphabetisation and distributes old, repaired computers to those who are economically and socially worse off.
- "Grande École Numérique": Supports schools and companies in teaching those with low qualifications and poor education ICT skills; this takes place in "digital factories".
- "Alliance for the Industry of the Future": Preparing companies for the digital age (based on a coalition of companies, scientists, and unions).
- Creation of a "Digitalization Council" in 2011 (https://cnnumerique.fr/missions/).

Germany

- Recommendations based on report by Comm. of Experts for Research and Innovation (EFI, 2016):
  - "Robotics in transition": Strengthen research and transfer / Modernise the training and support of lifelong learning.
  - "Business models of the digital economy": Give interested SMEs access to "business model academies" which teach implementation strategies for digital business models. / Work towards setting up a stock market segment for VC. / Encourage people to practise sensible ways of handling their own data as early as possible. / School curricula should pay more attention to fundamental digital skills. /

  - Understand computer science as a new key discipline and incorporate it more closely into the curricula of other training courses.
  - “E-government”: The Federal Government should greatly intensify activities to create and develop both a central e-government portal and an open-data portal, offering as many services as possible in concentrated form. The Federal Government, German states, and municipalities must agree on uniform interfaces for digitalisation.
- Interview with secretary of labour Andrea Nahles (Eubel & Haselberger, 2016):
  - Nation-wide centres for advising employees with regard to further education (provided by the German Federal Employment Agency).
  - Idea of employee accounts to finance further education or “time-outs”. Further education should focus on relevant future skills. More credits for lower- than higher-qualified employees.
  - Need to increase flexibility of working hours without undermining employee rights and introduce social security for self-employed persons.
- Further recommendations by Hochschulforum Digitalisierung (2016), Kultusministerkonferenz (KMK, 2016), and Bundesministerium für Wirtschaft und Energie (BMWi, 2016).

Great Britain

- “Tech Partnership”: A partnership of companies and universities which teaches students management skills for ICT businesses (accredited Bachelor and Master’s degrees), as well as training in primary/secondary school (for free). Specific goal of higher rate of female participation.
- Computing and programming as a mandatory part of children’s education, upskilling of teachers with regard to ICT skills. New curriculum at schools is developed in part together with companies and other stakeholders from the Tech Partnership.
- Strong private/public partnerships (techUK, Tech Partnerships, etc.).
- MOOC for unemployed ICT specialists/people from other fields to facilitate (re)entry into ICT sector.
- Unions offer courses to increase digital inclusion (in cooperation with state-funded organisations, such as “Online Centres”).

Netherlands

- Field laboratories where researchers interact with businesses to share their experiences and needs in working with new technologies. These laboratories are intended to identify the need for action with regard to long-term educational developments and need for social innovations.
- Collaboration between the Ministry of Economic Affairs and private companies to reduce digital illiteracy.
- Initiative of universities, political actors, and companies to annually bring 30,000 tech specialists into the labour market, increase STEM curricula at schools and “reactivate” older employees with ICT training to retain their competencies in the labour market.

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Appendix 3:
Transcript keynote speech Vivek Wadhwa

Vivek Wadhwa is Distinguished Fellow and professor at Carnegie Mellon University of Engineering at Silicon Valley and a director of research at Center for Entrepreneurship and Research Commercialization at Duke. The following transcript is based on his keynote speech at the SSIC Plenary Meeting on November 21, 2016.

Good, I'm going to give you a crash course on the future of technology. As a matter of background I've been at Stanford University and Singularity University researching the impact technology is going to have on entire industries. And my conclusion is that there is going to be more change in the next five or ten years than anyone imagines. Because technology is on an exponential curve.

[1st slide – The Six Million Dollar Man]
[Intro of TV show "The Six Million Dollar Man" is playing]

How many of you remember Steve Austin? (Laughing) At least in America it was one of the famous TV shows.

[2nd slide]
Why do I bring up Steve Austin? Because here's a prediction that Steve Austin becomes the reality in the year 2030 – 14 years from now. And Steve Austin is not the six million dollar man, he's a six thousand dollar man. This is how technology is advancing.

[3rd slide – The history of technology]
About the history of technology. Hopefully you have a chart that shows you the history of technology. See, this is an exponential curve. It took thousands of years to go from agriculture, to pottery, to plows, and mathematics. Over the last hundred to two hundred years we've had major advance after major advance after major advance. We simply don't comprehend the rapid pace at which technology is moving.

[4th slide – Moore's Law]
This chart over here shows you what you get for one thousand dollars on a computing device. In the year 2010, for one thousand dollars, you got the computing power of a mouse's brain. In the year 2023 for a thousand dollars you'll have the computing power of a human being. By 2050, if Moore's law continues, and you folks know the debates about Moore's law, how long it will continue, by 2050 if Moore's law continued you would have the computing power of every human being combined. Seven billion people. This is how technology is advancing. And the advantage that our computing devices have is that they network together, they communicate with each other in gigabits speeds. So think about what I just said. The iPhone 11 or the iPhone 12 would have the computing power of a human being. Alright? Within two years of that it will have the computing power of two human beings. Four human beings. So this has serious implications, because it makes a lot of impossible things possible.

[5th slide]
And this is the most interesting aspect of it. It's not just computing, it's not just our computers that are advancing according to Moore's law, it is everything that computing touches: Artificial intelligence, robotics, networks, sensors, synthetic biology. You have many different fields of science now on exponential curves. And what's happening is that these curves are intersecting, so you now have multiple technologies coming together and they are going to be disrupting industries. That is how the advances are happening right now.

[6th slide – The evolution of the telephone]
This is how the telephone has advanced. You know that we've basically gone from these old devices now to smartphones. Even poor people in developing countries own smartphones.

[7th slide]
But now, if you think about all the things your smartphone does, that you have everything from a video conferencing machine to a TV set, typewriter, all of these things are featured in your smartphone now.

[8th slide]
But I think the most amazing thing that has happened to the smartphone in the last five years is that it also became a medical device. Let me show you.

[9th slide – The telephone, a medical device]
You start with an encyclopedia of medical knowledge, I mean, if you go back to the year 2010 when, you know, phones weren't that smart, when computers weren't that smart, in that year if you went to a doctor to get some advice, the doctor would listen to you and give you a prescription. And you basically had no way of knowing what to do with it. You know, in the USA we get second opinions. Now, what do you do? You can go and google it and find out about all the medications you're taking, the side effects. You have the entire knowledge of the universe available to you for free. Almost at any subject that you want, you have unlimited knowledge available to you for free. Everyone in the world has it! It's not just here in the USA or in Switzerland. Everyone in the world has the access to the same knowledge at the same time. This has never happened before.

[10th slide]
In fact, you can go to the Apple store here in Palo Alto (I live in the Silicon Valley), you see entire chests filled with medical instruments. You have devices that can check your ECG or EKG, you have devices that can check your blood glucose, you have devices that can monitor your body's functioning – in a computer store! This was sort of unimaginable five years ago, that you go to a computer store and be buying medical devices there. But this is how technology is advancing.

[11th slide – Disruption of the pharmaceutical industry]
But the big thing that happened in 2015 was that Apple also entered the field of health care and pharmaceuticals. You know the way the pharmaceutical industry works is that they have a drug or compound that they believe can cure a particular disease. They test those specimens in the lab. If it looks promising then they start doing animal testing. We mutilate thousands of animals for the cause of science. And then after we've finished testing with animals, we start testing on human beings. Typically, clinical trial involves a few hundred human beings. It takes seven years and costs more than a billion dollars to get a drug to the point where it is ready to be released. And then what happens if the medication causes side effects, we read about it in the newspapers, we read a lot about people dying. The medical industry spends so much on these drugs until they are released, that they are hesitant to do anything dramatic to them. Before, we did not have that information. Now with one app on a smartphone we have information not about hundreds of people, but hundreds of millions of people. The entire pharmaceutical industry is going to be disrupted, because of an app on an iPhone or research kit. Because now you have the technology industry gathering information about medications, their side effects, how they work with each other, and all of the data is going to be used to analyze it and change the pharmaceutical industry. This is going to disrupt the pharmaceutical industry. You have a number of very famous, world famous Swiss companies that are in pharma. They are going to be disrupted because of the one app on an iPhone. Because now we have the information about how the drugs work. This is all it took, was for Apple to release this one app.

[12th slide – Sensors]
Next step: We won't need iPhone cases. We will have epidermal electronics. There are several universities and several companies that are now working on developing band aids and sensors in our clothing that monitor us 24/7. Within five years we will have little tags in our underwears and sensors in our shoes that monitor our bodies' functioning. And the data will be uploaded to the cloud 24/7. We will be monitored 24/7.

[13th slide]
Next step: The sensors will go inside our bodies. Imagine taking pills that go inside your bodies and they make high definition images of what's inside them. Imagine having pills that can navigate to a particular region of the body and deliver medications precisely where they are needed. See, right now when you went to the doctor and you were sick, if you had influenza, the doctor would have prescribed you antibiotics. That's standard treatment. So what you do is you poison the entire body to try to kill one particular type of virus. Imagine if you can go directly to the region of the body where you have the problem. And you deliver a tiny payload of medication to precisely where it's needed. By 2022 or 2023 we will have devices that can do exactly that. That they can navigate within the body. See right now you have pills that go inside the body, inside the intestines basically, because you swallow the pill and they can photograph everywhere it's going. They can't navigate the bloodstreams, because it's very complex to do that. There are several companies now working on being able to navigate the bloodstream and to go to any part of the body. There was a movie in the 1960s called "Fantastic Voyage" in which they put those human beings inside those shrunk, miniaturized submarines. That type of technology will be possible in the 2020s. We will be able to go and explore the body like never before.

[14th slide – Digital medicine]
Medicine is becoming digital – an information technology. You recall what I said about what happens when something becomes digital, when it becomes an information technology? It goes on the exponential curve. Medicine is now on this exponential curve. We will see more advances in the next ten years than we have seen in the last 100 years of medicine. We are in the midst of a major revolution in science and medicine because of these advances.

[15th slide]
Next step: When you have data, you use artificial intelligence to understand it. I'm going to be talking more about this. But soon we will have artificial intelligence physicians, we will have apps on our smartphones that are guided by AI software. For example: IBM Watson. IBM Watson has learned oncology and he can diagnose certain kinds of cancer better than any human being can. IBM Watson is now learning every other field of medicine there is. Within five years, our computers will be able to diagnose practically every disease better than a human being can. And the advantage of software is that software is practically free, that computing is becoming free. So with all the information we have on the cloud, we are going to analyze it using artificial intelligence. In the 2020s, our doctors – we are going to have human beings that provide some medical care but the majority of the analysis is being done by AI. It will become our doctor, it will become our physician.

[16th slide – Genome sequencing]
And then there is the human genome. You know there has been a race in the year 2000 between the US government and other labs and the scientist Craig Venter to sequence the human genome. The government spend 2.75 billion dollars, the scientist spent a hundred million dollars and the scientist took US government data and he won the race. It costs roughly three billion dollars to sequence the genome. What cost three billion dollars then costs about 800 dollars now. And at the rate at which genomics is progressing within five years we will be able to do this for practically free.

[17th slide]
This means that we have become data. And now doctors are becoming software. There is a major transformation happening in genomics and medicine because our genes have become decoded and now we're gathering all this data from sensor-based devices.

[18th slide]
We're headed at an era of genomic medicine.

[19th slide – Personalised medicine]
Here's how medicine will work in the 2020s, in the late 2020s. We will start with our genetic profile, our sequenced genome. Just like we will get blood tests, we will all have our genome sequenced. It will be a standard part of our medical treatment to have our genome sequenced. And then we will also have our microbiomes sequenced. You know the field of medicine I am most excited about isn't the sensors, isn't the genomics, it is the microbiome. You know I have been brought up in an Indian family. In my upbringing it was all about holistic health. You know, we believed that the human being is more than just symptoms. So you would cure the entire human body: Ayurveda. In Switzerland, in Germany you have had homeopathy. In the US homeopathy is like witchcraft. You can't mention the word because people think you're crazy. It is dark science. But you know, it doesn't matter, OK? The fact is that you have had the battle between holistic health and western symptom-based medicine. If you research what is happening in the microbiome, the microbiome is shattering many of the myths about medicine. Because suddenly we are realizing that there is more to the body than our symptoms, than our DNA. You know we have between two and ten times more microbes and bacteria in us than we have cells. If you look at the research papers that have been published over the last two to three years, you know for example where they had one mouse which had Crohn's disease and one healthy mouse. They took the feces of the healthy mouse and put it into the mouse with Crohn's disease and they were able to eliminate parts of the virus. They also took the feces from a healthy mouse and put it into an obese mouse, a fat mouse, and the fat mouse became thin. So this is all in its infancy, but what's being realized is that it may well be the microbiome, the microbes in us, that determine our health. The cure to obesity and the cure to cancer may well be the microbiome. Give it five or ten years and we will have conclusive evidence on this and we will be now including the microbes in our body in our treatment, and we will start looking at the body as a whole. This is why I am so excited about it. Because finally now we begin to look at something more than just our symptoms, more than just our genes. That the entire ecosystem within us, the rainforest in us, is being decoded and deciphered. And then you'll take your lifestyle and your environment. Then even though two people might have the same microbes, the same genes, one person gets sick and another doesn't get sick because of the choices we make. Because of the lifestyle choices we make. We may smoke, we may take any other sort of risks and we get sick because of our lifestyle and our habits. Imagine now if you can have an artificial intelligence analyze all of this information together and prescribe health. This is medicine of the 2020s. It'll be all based on massive amounts of data. And to me this is amazing.

[20th slide - Bionics]
Next step: Steve Austin. If you look now at Argus, which is a French company, Argus can restore eyesight, partial eyesight to people who have particular types of eye diseases, retina diseases. There are other companies that are now developing the ability for blind people to be able to see light. They can't recognize vision yet, but there are advances happening in vision, in hearing, in exoskeletons. There are several companies all across the world now who are building exoskeletons that allow people to regain movement. That woman over there in the video, which is hopefully playing, she is wearing an exoskeleton from a company called Exobionics from Berkeley, California. She was able to walk again using an exoskeleton. Again, if you were looking on a linear scale you would say that the technologies are at one percent and it will take 100 years for them to advance to the point in which we are at 100%. On an exponential curve six doublings before you end up at 100%. In other words, 14 years. So, within 14 years, we should have the ability to create bionic people. Just like what we saw in science-fiction. That's why I showed you the video, that you have to think exponential now, which also means that the costs of everything drops. When new technology advances, it becomes faster, it becomes smaller, and it becomes cheaper. The cost of everything is dropping exponentially. This is why I put that chart up, which shows that Steve Austin, 14 years, 6,000 dollars, because the cost drops. Now I was cheating a bit there, that 6,000 dollars was in 1970s dollars. In today's dollar it would be 350,000 dollars. But you get the idea. That that is what's happening to bionics and to human enhancements on an exponential curve.

[21st slide – Development of sensors]
This is made possible by the advances in sensors.

[22nd slide – Digital camera]
You take the first digital camera, it came out in 1975, it weighed four kilograms, it cost 10,000 dollars, and it was a whoppy 0.01 megapixel. What you have in your smartphone today is a billion times better. This is how technology is advancing.

[23rd slide – Accelerometers and gyroscopes]
The nuclear missiles that the United States had, were guided by accelerometers and gyroscopes. They cost tens of millions of dollars in the first generation and they weighed hundreds of pounds. What you have in your smartphones today is roughly a billion times better than what the US government had. It's a thousand times more accurate than what we have in our nuclear missiles. Maybe we should upgrade our nuclear missiles to include iPhone technology in them, because what we have today in our smartphones is far more accurate than what we have in our nuclear missiles.

[24th slide – GPS]
GPS. The first commercial GPS came out in 1981, it cost 120,000 dollars, and it weighed 53 pounds. What you can buy on Alibaba today for less than one dollar is a thousand times more accurate than the first commercial GPS. And when you add apps to it, the apps stop you, guide you, and they can provide you with navigation information. This is the beauty of technology.

[25th slide – Sensors in smartphones]
If you take your smartphone apart, and I strongly suggest you don't do this at home, you would find in it sensors that would have weighed hundreds of pounds and cost hundreds of thousands of dollars just 30 to 40 years ago. This is how technology is advancing. What would cost, just 30 years ago, missions of dollars, now costs practically nothing. And these are features in our smartphones. We have supercomputers in our smartphones, we have all of these sophisticated sensors in our smartphones now.

[26th slide – Smart cities]
Here's what's possible: To build smart cities. You know we have been talking about smart cities for a long time. That there are all sorts of scientific papers and exhibitions on smart cities. The assumption was that smart cities would cost billions of dollars. We can change all those assumptions now, because now you can build smart cities for millions of dollars. Literally. The sensors necessary to monitor heat, sound, noise, traffic, pollution, chemicals, radiation, they are inexpensive. A sensor typically costs a few euros, a few dollars for the most sophisticated sensors. And the sensors are now connected together through WiFi. They can now be interconnected to centralized systems so you can start monitoring everything that's happening. You can now create smart buildings for practically nothing. You can create smart neighborhoods, smart cities for practically nothing. And we don't need governments to do this anymore, we don't need academics to do this anymore, entrepreneurs can do all of this now. This is what's possible using these sensors I've been talking about.

[27th slide – Robotics]
Robotics. When I was young I dreamed about having R2D2 as my friend, Rosie the robot cleaning up after me. When I grew up all I got was a stupid vacuum cleaner that goes round and round. A Roomba vacuum cleaner. What went wrong, why don't we have these robots we dreamed about when we were young?

[28th slide]
The reason why we don't have the advanced robots we dreamed about when we were young is because the computing power necessary to do voice recognition and face recognition would require to create super computers. The sensors necessary to detect what's happening around you were extremely expensive, they were big and bulky. But guess what! In your pockets now you have sensors that can do all of that. By my estimate, this is just a rough estimate, the smartphone that you carry in your pocket, this device over here, is more powerful than 40 great supercomputers. So we have the ability to build these robots now, the ability to build these advanced machines that we dreamed about in science fiction.

[29th slide]
As of today, it is cheaper to do manufacturing in Europe and the USA than in China, because of robotics. This is something that very few people realize. What we do right now, we ship our raw materials to China, all across the oceans, and then we use cheap labor over there to manufacture the goods and then we ship them back. We pollute the seas and we delay the process of manufacturing by weeks because we're taking advantage of cheap labor. With robotics everything has changed now, you can manufacture in the USA and Europe.

[30th slide – Robotics in manufacturing]
If you look at the state of the art robots now, for example the YuMi which is being built by ABB Switzerland, YuMi is now dexterous enough to thread a needle. You know four years ago we had read about Foxconn which said it would replace one million workers with robots – it never happened. We thought it was a hoax. The reason why Foxconn could not do that was because robots of four years ago did not have the dexterity for circuit board assembly. YuMi can assemble circuit boards now. And there are a whole range of new robots that are coming on the market that can exactly do what human beings can do. And they cost practically nothing. YuMi is about 40,000 EUR. So these robots now are becoming cheaper and within the next five years it would not make sense to remain manufacturing in China any more. This is a major opportunity for Switzerland. It's a major opportunity for Europe to bring manufacturing back and to use robots to do what is done by cheap labor in China now.

[31st slide – Robots as companions]
They are becoming our companions. Yes, that will become a multibillion dollar industry. We will now be having robotic companions. Robotic sex will probably be the fastest growing industry there is. Because we will be able to 3D-print the robots in the next ten years or so.

[32nd slide – Self-driving cars]
Chauffeur self-driving cars are reality. I drive a Tesla Model S. When I get on the highway I put it into the auto-pilot and it drives itself, literally. When I'm in my car on the highway I'm looking on what's happening around me, or I'm glancing at my e-mail. I have a big screen there on which I have e-mail. The car does the driving by itself. Within two or three years, the car will drive itself even on the local roads. In Silicon Valley we're beginning to take self-driving cars for granted. In Europe you've seen early signs of them. And there's still skepticism about whether they'll work or not. You still have academics saying there will be 30 to 40 years till they work. False! It will be less than five years before cars are a 100% autonomous. It will be less than 15 years before we start debating whether human beings should be on the road at all. This technology is advancing exponentially because of machine intelligence. It took 15 years or so to get the first generation of self-driving cars. Now you have start-ups coming from all around the world that are teaching their cars to drive themselves using machine intelligence. Self-driving cars will take over our roads in the 2020s.

[33rd slide – Drones]
Drones. Delivery vehicles. You know in the developing world you have 10–20% of the traffic that's basically delivering goods. What if you could just drone it over? Drone-based delivery will become legal in the United States within the next two years or so. You have all the major transportation companies experimenting with drones. So imagine now waking up in the morning, clicking on an app and having your morning latte delivered to you on your back porch by drones. This will become practical within the next four or five years and it will become legal in most countries over the next five years. So this is going to replace a big segment of the transportation industry. Because drones are also advancing exponentially. They're getting more and more sophisticated. They are able to carry more weight. We're developing drone-based collision systems. We're developing all sorts of new technologies which will allow our drones to navigate our roads. We'll probably have drone-ways on our roads by which they are restricted to certain passage ways and they can come to houses when they're given permission and can deliver their goods. This is the next five years or so. This will dramatically revolutionize the transportation industry.

[34th slide – 3D printing]
Printing.

[35th slide]
We now have 3D printing. 3D printing is still very slow and cumbersome. But 3D printing is advancing not on an exponential pace, 3D printing is advancing slower than many of the other technologies are. Because it's still physics-based. But if you give it five or ten or 15 years, we will be able to 3D print everyday goods. Plastic, glass, titanium, human cell will be 3D printed.

[36th slide]
3D printed cars. Already now you know some companies demonstrate to be able to 3D print cars. But it's still not practical. It's still very cumbersome and you only print in plastics. Within 15 years or so we'll 3D print metals and we'll able to do layer by layer printing. So we'll be printing the entire skeleton of the car using 3D printers.

[37th slide]
3D printed houses. Several companies across the world are demonstrating that they can 3D print buildings. The Chinese have been most aggressive in this. If you look at what WinSun did, a Chinese company, WinSun stole some technology from UCLA and then they demonstrated they could print office buildings one floor a day. They demonstrate this already. It's still very cumbersome, it's still very limited in the materials you can use. But if you give it ten or 15 years, it will become practical to houses and office buildings using 3D printers. This is coming.

[38th slide – Synthetic biology]
Synthetic biology. I don't know if you folks are tracking CRISPR and synthetic biology or not...

[39th slide – DNA editing
...but this is the most amazing technology of all: Editing DNA. I'm sure you folks have been following some of it, but the basic way this is advancing is shocking everyone in the industry. In Silicon Valley where we're used to have exponential advances, even here like in Berkeley where CRISPR was developed and MIT. I know the scientists have been astonished at the rate at which this is advancing. That no one ever has anticipated that we will be editing human beings in the year 2016. The Chinese now have announced that they're editing human beings for cancer, basically lung cancer. They already now started the trials of edited genes trying basically to cure lung cancer.

[40th slide]
These are the things that are already being produced: Micro pigs, you know they were taking big pigs and make it smaller, some extra-muscular beagles and so on and so on. This is all happening right now.

[41st slide]
This is what's possible. And what scares me the most is human DNA editing, human genome, human editing. Because even though scientists have agreed to put a moratorium on this I don't think that the governments are really listening. The Chinese in particular have gone crazy with this. It will not be long before – you know with cloning we were able to have a moratorium to keep it under wraps, cloning was still slow, cumbersome, expensive. CRISPR Cas9 genome editing is inexpensive. It costs less than 10,000 EUR to set up a CRISPR lab. So there are hundreds of these all over the world. They are now experimenting with practically every life form there is. So this is on an exponential curve and this is going to be shaking up many industries. Because we'll be building and producing new types of synthetic fuels, we'll build and produce new types of synthetic plants, we'll be producing synthetic human beings. So this is something you folks should be looking into because it's really scary how fast this is happening. And it is happening faster than anybody has anticipated it would happen.

[42nd slide – Artificial intelligence]
Artificial intelligence. What's AI? AI is machines with the type of thinking human beings could do.

[43rd slide]
You know, we heard about AI in the 1980s and then in the 1990s we heard about the end of AI – the "AI winter" it was called. Because there were so many predictions about AI was going to take over the world, all the science fiction movies and so on, so we thought AI was a hoax that AI was not happening. Everything has changed in the last five years. Here's what has changed: First of all AI researchers discovered that the best way of writing AI was not the traditional way. You know when Deep Blue beat Garry Kasparov at chess, the code for that was written sequentially. The way you wrote artificial intelligence ten or 20 years ago, was that you coded every particular condition. You created a flow chart. That "if this", "then this", "if this", "then this, "if this", "then this". And you wrote millions of lines of code. And with super-fast computers, it happens so fast, it seemed like science fiction. It seemed like it was artificially intelligent. That was the old AI. About three, or four, five years ago, scientists started applying neural networks to AI. There were papers as recently as 50 years ago about neural networks and AI, but it was not practical because the computing wasn't there. So then about five, six years ago you had Nvidia developing the graphical processing unit for game controllers. You know the games that our children play? They have led to the revolution in AI. Because the technology necessary for doing massively powerful computing was in those game chips, the GPUs, the graphical processing units. So what the researchers did was that they started applying the GPU technologies to neural networks. You know I assume you know how neural networks work, how the brain works, that we have layers of neurons in our brain, which are analyzing information. So you have the first layer of neurons recognizing the basics of an object, the second layer now refining it, and then it goes through layer after layer after layer and eventually the human brain recognizes an object and then it trains itself to know what an object is. This is how our brain works. So they started to apply these techniques to artificial intelligence, over the last five years or so. And then there had been more advances in the last three years in AI, than in the previous 30 years, because of neural networks. That the algorithms have been improved, that the entire neural network deep learning field has gone on this exponential curve. In the tech field, you know Google for example, if you look at the way a Google search works, initially it was hard coded, it was page ranked. You know Larry Page had invented this technique for rating websites that was really done using the old generation of artificial intelligence. So they had millions and millions of lines of code, which basically decided how to rank a page. Over the last two years or so they started rewriting page rank to start using neural networks. Google has started rewriting all of their software to take advantage of neural networks. Now here's the good thing about neural networks: They don't need millions of lines of code anymore. A neural network can be written for as little as 600 lines of code, not millions of lines of code. But the scary thing about neural networks is that no one understands how they work. Because they develop their own algorithms, they develop their own weightings, their own rankings. So when AlphaGo defeated human players, the Google scientists did not know how AlphaGo worked, why did it win, why did it make the decisions it did, they did not know. Because the neural networks program themselves. So this technology is now being applied to every field of artificial intelligence, including self-driving cars. That you basically throw massive amounts of data at the network, it's learning by itself, its training itself, the same way as a child learns, the same way a human being learns. This is how artificial intelligence is now working. And all across Silicon Valley every type of data there is, is being now analyzed using neural networks. This has happened in the last 12 months. Right? So forget about scientific papers, forget about scientific discussions, the academics do not understand what has happened to neural networks and artificial intelligence, because by the time you publish a paper it takes two or three years, the technology has changed already. Silicon Valley is in a state of shock. If you read the blogs by the leading venture capitalists, the leading researchers over here, they are in a state of shock as to how far and how fast neural networks and deep learning are advancing. They begin to apply it to everything.

[44th slide]
AI is everywhere. AI is already now in traffic control systems, in Siri, in all of our technologies. Now in the last year or two years they started retrofitting all of the AI applications to use neural networks.

[45th slide – Augmented reality]
And the next big thing in Silicon Valley is virtual and augmented reality. I don't know, Claudia, do you have virtual reality headsets at your institute? Because virtual reality headsets right now are very cumbersome, they're big, they're bulky, and they're clunky, if you use them too long they cause nausea. So my prediction is that in 2017 we're gonna declare virtual reality to be a failure. We're gonna be disappointed in it. We're gonna talk about how it was so promising, but nothing ever happened. In 2018 we'll have version two of these technologies coming out, which are going to be smaller. In 2019 we're gonna have version three, which is gonna blow people away. Because version three will be like the eyeglasses you wear, they'll use nano materials and they'll basically turn dark and take you into holographic worlds. The computing power will be eight to 16 times faster by 2020 than it is today. So you won't need these massive desktop computers. You'll have small smartphone type devices that can provide all the computing power to do high-definition rendering of virtual reality. In the early 2020s we're talking about wearing eyeglasses, not headsets, eyeglasses, that take us into virtual worlds. This will change everything about the way we communicate. The meetings we'll be having in 2022 like this, you know, we should do it on the moon or on mars, because we'll be able to interact with each other it'll be through holodecks and holographic exchanging of information. This is how fast virtual reality is advancing. Next year, Magic Leap will be releasing its augmented reality technology. What they did in augmented reality is that they developed new techniques for displaying graphics. And it's going to be an amazing breakthrough. What we're gonna see from magic leap next year, is gonna take us to the next level. But, again, this is all on an exponential curve, because now we'll apply AI to it, we're now using new nano materials, and we apply also sorts of new techniques with faster computers. So virtual reality should be on your radar screen. Because it's going to be transformative to everything: To the way we live our lives, the way we receive entertainment, to the way we have our meetings. Entertainment right now, when you watch a movie, you sit back and you watch the screen. The next generation of movies in the 2020 we're gonna be in the cast, we're gonna be in the back seat of a car chase. So we can experience it virtually. This is how dramatic virtual reality is.

[46th slide – Grand challenges]
Now let's talk about humanity's grand challenges. I live in Silicon Valley where tens of billions of dollars are wasted on mindless apps. If you read my writing, if you go to my website wadhwa.com, you'll see that I'm an optimist. I'm also very pragmatic about the dangers of technologies and I'm very critical about Silicon Valley. One day, I'm talking in Silicon Valley's praise, the next day I'm criticizing it. Because I see billions of dollars being wasted here on stupid things. We're all building the same social media apps, we're building photo-sharing apps, the same stupidity. We're not solving the problems of the world. The reason for that is because Silicon Valley doesn't understand the problems of the world. It doesn't understand hunger, it doesn't understand poverty, it doesn't understand the fact that the majority of the world's diseases are caused by water-borne viruses, it doesn't understand that energy is not about having solar panels on your roof, it's about providing lighting to people and children who come home in Africa and who can't study. So we are out of touch with the needs of the world. But here's what the good news is: That technology is democratized now. Now, wherever I go all over the world I see entrepreneurs using sensors, using artificial intelligence, using all other advances to build world changing advances. This is the most amazing thing that has happened in the last two years or so. Innovation is globalizing.

[47th slide – Energy]
Let's talk about energy, ok? Which is the number one reason why we have wars right now. It's for energy. And we're obsessed with fossil fuels. This chart over here shows you the energy resources of our planet. We receive more than a thousand times more energy every day than the entire planet consumes in a year. It comes from the sun. So far we've been obsessed with focusing on petroleum, because that's the most efficient way of using energy. But this is changing. Solar is on an exponential path, this is something we don't understand over here. In Europe you went from excitement about solar to pessimism. You had Italy and Germany, leading the pack and now there's a backlash against solar. It doesn't matter.

[48th slide]
This is how solar is advancing. The cost of solar has dropped more than 99% over the past 35 years, the number of installations is doubling. As the number of installations is doubling, the price drops 15–20%. As the price drops, the number of installations doubles.

[49th slide]
The good news is that it isn't Europe that's leading the chart anymore, it isn't America, it is Asia. India and China collectively now are leading the chart on solar. So it doesn't matter if there's a political backlash in Europe, it doesn't matter if Donald Trump tries to revive the coal industry, it doesn't matter. The growth right now is the developing world. So this is an unstoppable force.

[50th slide]
As scientists you're gonna find this to be crazy again. You're gonna think he's a nutcase. But here's an article I wrote about energy. What I said was that we're 14 years away from being able to generate 100% of the world's energy need from solar. 14 years – 100%. How's this possible? Because solar is on an exponential curve. You know you have the IEA, you have all of the regulatory bodies, you have all these experts on solar, which keep forecasting the advances of solar, and then they keep revising their forecast. What they don't understand is that solar is on auto-pilot right now. It doesn't matter what the experts say, solar is on an exponential curve. By 2020, four years from now, solar will cost half as much as it does today. By 2030 it will cost one hundredth or less of what it does today, on this exponential curve. I wrote this article for the Washington Post about the coming era of unlimited and free energy. It created uproar because – by the way I also have a column for the Washington Post and I do a lot of writing, you can read my articles, they tend to be quite controversial (laughs) but they're mostly correct – so when I wrote this article it had an uproar in the United States because the fossil fuel industry was very upset. Because I can influence policy in Washington D.C. with my articles, so they objected to this article because I also said that the utility industry will go bankrupt. So they were very upset at me, saying how can it be, this guy is an idiot, he has no idea what he is talking about. Look at what the experts say. My answer is, ok, what their argument was that the sun doesn't shine when it's not sunny, the wind doesn't blow when it's not windy. True. So their argument was you still need the utility industry because you can't afford to store energy. True. Look at the next slide…

[51st slide – Energy storage]
This is the cost of storage. It is dropping on an exponential curve. Why don't we see this? You folks are scientists, why do we do these stupid predictions? You know Saudi Arabia, if you look at the papers that they publish, the fossil fuel industry, they're talking about 40 years from now only one percent of the cars will be electric. Because they are looking at it linearly. Why can't we see exponential curves? The cost of storage is dropping exponentially. Next year when the Tesla Giga Factory opens the cost of storage will drop by 40%. By 2020 the cost of storage will drop by 60%. 2020, 2022 in that two year time frame if you are building a new house in Switzerland or here in Palo Alto the cost of solar panels will be about five or six thousand dollars. The cost of storage for those solar panels, enough for a house, will be five or six thousand dollars. So in other words, for ten to fifteen thousand Euros, including installation costs, you'll be able to have an entire house off grid. Think about what this means to the entire utility industry, the energy industry. This is without government subsidies, this is with Donald Trump, this is with the mad man who is trying to stop energy from progressing. By 2020, 2022, you'll be able to have entire houses off grid. This sounds like science fiction, doesn't it? You know where I live here in Menlo Park, I actually live in a passive home. It's the specifications of the passive house institute of Europe. It's a house that is built the same way like the houses in Norway are being built, very efficient, you know one foot thick slabs, so it can leak very little energy. And then I have solar panels and I drive a Tesla. My energy costs are almost zero. Without the Tesla they are negative, with the Tesla they average about 50 dollars a month, 50 Euros a month. That's what roughly my energy costs are. I'm already living in a clean energy future. In the next five or seven years, it will be possible for people all over the world to live this clean energy future. And then it's gonna decimate the costs of petroleum, because what it takes for an entire industry to get whipped out is future growth stopping. So I'm not saying we'll stop using petroleum that will continue for another 50 years or so. What I'm saying is that the rate of increase of usage will drop dramatically, it will begin to decline slightly in the early 2020s, it will drop dramatically in the late 2020s. The cost for petroleum will be down to ten to 20 dollars a barrel. It will stay there. The entire fossil fuel industry will be decimated. This is a 99% percent certainty I'm telling you this. So who is talking about this, which of your scientists are making these predictions? No one dares to say this. But it is so obvious, look at the data! Look at the exponential curves! That's the good news.

[52nd slide – Health care]
Now let's talk about health care. In the United States now, one of the big things that Donald Trump announced is that he's going to end Obamacare. I mean, it's so stupid, you know, in Europe my friends are shocked, that we're talking about taking health care away from people. And this is what the country is voting for. These mad idiots in power, they're gonna take health care away from people, because the health care system will bankrupt America. Stupidity. Here's what's happening with health care as well. The sad situation right now is that billions of people don't have access to quality diagnostics. But let me show you what becomes possible with sensors. I'm going to take you to India now to show you the problems of India. In India, for example, in the villages they don't have – in Switzerland and the US when a woman gets pregnant she goes to the doctor, they do a blood test and if she has any abnormalities they fix it. In India and in the developing world there are hundreds of thousands of women that die from pre-eclampsia. Pre-eclampsia is a disease women get when they're not treated. So one of my friends was a biomedical engineer at Arizona State University and an Indian scientist. What he noted was that the medical equipment he was using here was very expensive, extremely expensive, tens of thousands of dollars. And the way the hospital would charge for it was thousands of dollars for simple tests. He looked at the sensors on the medical instruments. He said these are really cheap, I can google them and he found the manufacturer of the sensors of the medical equipment. Like the ECG monitors, the testing kits for diseases and so on. He said why can't I use my own computer to analyze this, I buy the sensors in Japan or in China and then connect them to my laptop.

I should be able to use my laptop to analyze the data. The sensors are essential, therefore they should be exactly as accurate as the medical equipment is. That makes sense, doesn't it? But he couldn't get funding for it. So he went back to New Delhi.

[53rd slide – Portable laboratory]
He built a device called the Swasthya Slate. What he proved was that you could buy medical sensors off-the-shelf, and use the computing power of your laptop, he actually had a tablet, he connected his tablet, and he used cloud computing to upload all the data, and he built AI apps to start analyzing the information. He built a device called the Swasthya Slate.

[54th slide]
Here's what the device does: It does the most common medical tests, which are needed in hospitals, HIV, dengue, malaria, syphilis, typhoid, blood glucose, blood hemoglobin, EKG, temperature, the most common tests that you would need in a hospital, this device does. It costs 600 USD. 600 USD that does the same test as the medical equipment does. He had it tested by different labs in India, it was exactly the same as western medical equipment. Because it was exactly the same test. He built a platform for inputting the data and they built simple tools, which anyone could understand the output of it.

[55th slide]
He got permission to use this in Northern India in Jammu and Kashmir. So there was a study done in one village in Punjab, in which roughly 100 women were dying every year from pre-eclampsia. So they brought this device in, they tested every woman that got pregnant, the cost of testing was nothing, we are talking about one or two Euros for all the medical tests you could think of for a pregnant woman. It would take 14 days before to get a woman tested, because in your hospitals you have all the medical equipment in one place, in villages you only have certain types of equipment in one place, you go to another clinic, to another clinic, so it would take 14 days for a woman to get tested, for all the pregnancy-related testing. After the device was brought in…

[56th slide]
…what would take 14 days, would take 40 minutes. Because you could do the testing immediately and get the results back immediately.

[57th slide]
So there was a study done in this village in which roughly 100 women were dying every year of pre-eclampsia. They tested 1,000 women that year. They found 120 to be pre-eclamptic, they treated every one of them and there was zero deaths in that village in that year. A 600 USD device saved 100 lives in one village. So this device, it's being used all over Northern India, they are shipping about 100 units every month right now. I've taken it to Latin America. One of my friends over there owns the largest medical system in Peru. They've been using it in the hospitals there the last six months informally. They found it to be exactly as accurate as the expensive medical equipment. They are now getting the equivalent of the FDA approval in Peru. They are planning to role it out all over Peru. I'm also taking it to Mexico, I'm also taking it to Brazil. After its use in Latin America we take it to Africa, and then we'll bring it to Europe and the United States. This device will sell for 1,000 USD when we bring it here. A thousand dollar device disrupting the entire medical system because anyone and everyone can do their own testing with a device like this. We don't need the expensive testing anymore, we can now have telemedicine and home testing kits or testing kits in your shopping mall and so on and so on. This is what's possible now to disrupt entire industries.

[58th slide – Disruption of industries]
Every industry will be disrupted. This is the impact on every industry, every industry will be disrupted.

[59th slide – Disruption of manufacturing]
Manufacturing.

[60th slide]
The robots will take over. As I talked about this, what's possible.

[61st slide]
China is advancing the progress of robotics, but you know the good thing is we don't need the Chinese robots anymore. Our robots are as productive as theirs are. Our robots don't join labor unions, they don't complain, they don't want 30 hour work weeks.

[62nd slide]
Next step after the robots take over, we'll have 3D printers that do everyday printing.

[63rd slide]
And then in the 2020s, the robots will go on strike because 3D printers will take their jobs away. (Laughing) So I'm talking about two waves of disruption to the manufacturing industry. Wave one is the robotics and then right behind it is wave two with 3D printing.

[64th slide – Disruption of transportation]
Transportation.

[65th slide]
Cars and computers are becoming one. Why did we hear about project "Titan", which is Apple's car? Because Apple has realized what Tesla taught it. That a car is an iPhone on wheels. With electric cars with motors, the entire – I mean my Tesla gets software updates every two weeks or so and I get new features in my Tesla. It's amazing, to wake up in the morning and your Tesla has new, advanced features in it. This is what's happened to transportation.

[66th slide]
Next step: Electric cars, self-driving cars. In the 2020s we can expect that we'll have cars that can go about 100 to 200 km that cost about 15,000 EUR. In the 2030s they'll be down to 5,000 EUR for a self-driving electric car. This is how it's advancing. What will also happen is that with the sharing economy we won't need to own cars anymore. We'll be basically sharing our cars. So we're talking about major disruptions to the entire transportation industry happening in the next five, ten, 15 years or so.

[67th slide – Summary]
I'm gonna stop here for a Q&A. The bottom line is there are trillion dollar opportunities, disruptions happening everywhere, and entrepreneurs can make this magic happen.

End of presentation

Digital competences

Paper commissioned by the Swiss Science and Innovation Council SSIC

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Professor Sabine Seufert, University of St. Gallen

With an introductory comment by Professor Alexander Repenning, University of Applied Sciences and Arts Northwestern Switzerland and University of Colorado

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About the authors

Dr. Sabine Seufert holds the Chair for Business Education and is Director of the Institute of Business Education and Educational Management at the University of St. Gallen. At the Institute she leads the swiss centre for innovations in learning (scil), initiated and founded with the support of the Gebert Rüf Foundation.

Seufert studied business administration, information management, and pedagogy at the University of Erlangen-Nuremberg and received her Ph.D. in information management at the University of Muenster in 1996. In 2006 she finished her habilitation at the University of St. Gallen (venia legendi in business education and educational management).

After her academic studies she worked two years as higher education teacher at vocational schools in Bavaria and received her teaching diploma in 1997. From 1997 to 1999 she was co-founder and project manager for the Learning Center at the University of St. Gallen. From May 1999 to 2001 she was responsible for the Executive MBA in New Media and Communication under the lead of Prof. Peter Glotz at the Institute for Media and Communication Management at the University of St. Gallen. In 2000 she stayed as visiting scholar at the Stanford Learning Lab and in 2008 as visiting professor at the University of Southern Queensland, Brisbane.

Dr. Alexander Repenning is the Hasler Professor and Chair of Computer Science Education at the PH FHNW (School of Teacher Education at the University of Applied Sciences and Arts Northwestern Switzerland), and is a computer science professor at the University of Colorado. He is directing the Scalable Game Design Initiative at the University of Colorado.

Repenning's research interests include education, end-user programmable agents, and artificial intelligence. He has worked in research and development at Asea Brown Boveri, Xerox PARC, Apple Computer, and Hewlett Packard. Repenning is the creator of the AgentSheets & AgentCubes simulation and game computational thinking tools. He has offered game design workshops in the USA, Mexico, South America, Europe and Japan. His work has received numerous awards including the Gold Medal from the mayor of Paris for "most innovative application in education of the World Wide Web", as well as "best of the best innovators" by ACM and has been featured in WIRED Magazine. Repenning has been a Telluride Tech Festival honoree for contributions to computer science. He is an advisor to the National Academy of Sciences, the European Commission, the National Science Foundation, the Japanese Ministry of Education and the Organisation for Economic Co-operation and Development (OECD).

The authors contracted by the Swiss Science and Innovation Council to produce the present paper/introductory comment bear full responsibility for their respective contents.

Introductory comment by Professor Alexander Repenning

In her position paper on Digital Competences, Dr. Sabine Seufert is identifying some of the key challenges posed to society by the digital revolution. She paints a somewhat alarming picture particularly with respect to employment. Just like most revolutions, even with the best of original intentions, the outcome of this revolution, due to its enormous speed, may not only be hard to predict but may have dire consequences for society. Will jobs be lost due to massive automation of mechanical chores through robots or will humans engaging in cognitive processes be replaced by artificial intelligence? Then again, the digital revolution may result in a new kind of digital prosperity transforming society for the better. To cope with this intrinsically difficult process, Dr. Seufert is suggesting a number of guiding questions and offers a vision for educational policy makers based on the notion she refers to as "digital competences 2030."

Dr. Seufert's vision to make the best of the digital revolution is the notion that she calls augmentation, by which she means a yin and yang-esque symbiotic complement of human abilities with computer affordances. Quite carefully, in her vision, she is exploring a societal sweet spot of human-machine interaction explicitly avoiding technology use cases where machines are replacing humans. Innovation in IT makes machines evolve at unnerving rates to become more versatile, faster, better, and smarter. The only means for humans to participate meaningfully in this ever changing symbiosis will be through systemic education resulting in crucial digital competences relevant to the 21st-century workforce. Digital education, that is the process of acquiring these digital competences, is the key to augmentation.

At this point, it is still less clear what these digital competences should be. Among other things, Dr. Seufert calls out the notion of computational thinking. This concept, embodying the idea of problem-solving with computers, has not only become highly popular, particularly in the USA, but has also become the core idea of numerous well-funded government initiatives advancing digital competences. Empirical studies assessing digital skills, such as the ICILS and the PISA study cited by Dr. Seufert, suggest average performance of Swiss students. However, these studies are focused mostly on application-use competence, e.g., how to use products such as Microsoft Word, or social media competence, and provide limited insight into the computational thinking skills of Swiss students. Fortunately, newer versions of theses studies, including the assessment of computational thinking, are currently under development.

A layered spiral curriculum approach is suggested as the foundational for a digital competence framework. Starting with digital literacy, already at the primary school level, students gain critical understanding of technology including some basic understanding of programming as well as the use of artificial intelligence, statistics, natural language processing and data security. Then students move on to digital citizenship as means to understand responsible use of technology to solve real world problems. Moving further still towards higher education, students gradually develop a sophisticated sense of critical thinking, including computational thinking, as well as social and self-competence to become responsible and self-determined personalities. Dr. Seufert does list a number of potential challenges accompanying this framework. Of particular concern is teacher professional development to successfully train teachers that can employ digital media for the purpose of education in their classrooms effectively. An additional concern is rooted in common teaching practices, which are not only slow in the uptake of new ideas but also often even hostile towards innovation.

Conclusions and comments

The position paper closes with six conclusions aimed at educational policy makers. Each conclusion is listed in their short form (italics) plus comments:

1. Awareness: *Leaders, educational policy makers, have to develop a vision for the successful partnership of human and machine, with the aim to win synergy through complementary competences.* A symbiotic nature of human abilities and machine affordance interactions is clearly desirable but the scope, and speed of machine evolution make the co-evolution of human-machine interaction nearly impossible to predict. Politics and education typically follow reactive and not proactive patterns. This will make the development of appropriate visions quite difficult and will require leaders and educational policy makers that are deeply connected to the scientific community.

2. Curriculum: *A national digital competence framework as a spiral curriculum with transversal educational policy status should be developed.* Developing this kind of curriculum will be essential but it will be challenging to inject a new competence framework into the existing curriculum landscape in Switzerland (e.g., Lehrplan 21). Switzerland is still in the lengthy process to adopt the current Lehrpan 21 in the 21 German speaking Kantons. However, with relative small conceptual shift, the suggested digital competence framework could be constructively aligned with the "Informatik" and "Medien" subject areas of the Lehrplan 21. The Lehrplan 21 does provide the necessary flexibility to enable this kind of adaptation.

3. Assessment: *New ways of assessment and measurement of digital competences are needed. Enhanced formative assessments (based on national assessment banks) need to be integrated into the assessment systems. In general, the grading system in education needs a dramatic change from standardized testing to graduation portfolio systems.* Progressive research in the learning science is already heading in this direction. For instance, instruments have been developed and validated to enable formative as well as summative evaluation approaches for computing computational thinking. These approaches, instead of administering traditional tests on programming skills such as multiple choice tests, allow students to simply create programming projects such as simulations and then have certain algorithms identify concepts expressed in their code to gage competences automatically.

4. DIY learning: *Do-it-yourself (DIY) learning should be encouraged in primary, secondary, and higher education institutions. A new mindset of creativity, innovation, and self-organisation (sharing culture) should be actively fostered in order to promote school and organisational development.* The theoretical value of designing/building based learning approaches has been recognized in the learning sciences for a long time. Constructivist, and constructionist learning have been advocated by researchers such as Papert as early as 1970. Most key challenges emerge from practical concerns implementing constructionist ideas in the context of innovation-resistant organizations such as schools. The benefits of constructionist learning are often difficult to gage, making it difficult to justify real, or perceived, overhead in teaching and evaluation. The Maker movement has brought back some of the constructionist spirit but has not yet developed a strong learning model anchored in the learning sciences.

5. Teacher Professional Development: *One of the key success factors are school teachers. A major initiative for the competence development of teachers is needed. The conceptualization and design of suitable education training measures for teachers require a systematic approach to the professional development of teachers.* Without any doubt, teacher professional development is one of the key enablers of digital education. In the short run, in-service teacher professional development, e.g., short summer workshops, will enable a small number of self-selected teachers to progress into this new territory. In the longer run, however, it will be necessary to integrate the training of pre-service teachers into required classes offered by schools of education. Systemic impact requires approaches exposing all teachers.

6. Research: *Digital competences at an organizational level need further investigation: Closing the "Society-in-the- loop" gap and learning analytics or academic analytics are examples of the new research field "digital competences at organizational level."* This research field is extremely important but vast and completely underdeveloped in Switzerland. The following section provides an elaboration of this point providing some suggestions on how Switzerland could transform its research potential in this field.

Opportunities and challenges for Switzerland to become a digital competences leader

Overall the position paper makes a compelling case for being more progressive with the digital competences education in Switzerland. However, an even more reforming position could be to become a digital revolution leader. That is, instead of focusing mostly on measures to catch up with the revolution one could employ the unique innovation potential of Switzerland to formulate a truly transformative approach aiming at a leadership position. The digital revolution hinges on Computer Science Education (CSE) and on Computer Science Education Research (CSER). Given its unique infrastructure and established culture of innovation (e.g., a high number of patent applications per capita), there are three opportunities that amount to a very high potential for Swiss leadership:

1. High degree of Research Funding Levels. The US National Science Foundation has a $7.4 billion (2017) budget compared to $0.98 billion (2016) of the Swiss National Science Foundation (SNSF). Adjusted for population, that suggests a per capita research budget of $21per person and per year in the USA and $117 in Switzerland. This is a five-fold advantage for Switzerland to fund basic research. To make matters worse for the USA, President Trump has proposed an 11% US National Science Foundation (NSF) budget cut for 2018.

2. National Computer Science Curriculum. The Lehrplan 21 is a national level (elementary and secondary school) curriculum serving the 21 German speaking Kantons of Switzerland. Adoption is not 100% but is growing at a steady pace. The Lehrplan 21 does include Computer Science and Media competences that are highly relevant to a digital competency framework.

3. Systemic Pre-Service Teaching Capacity Creation. Swiss Schools of Education are starting to offer required computer science courses to pre-service teachers. For instance, the PH FHNW, starting in Fall of 2017, will require all of its 800 pre-service elementary school teachers to become fluent in Computational Thinking. A dense network of schools of education could result in an unprecedented, systemic level of Swiss-wide teacher professional development in Computer Science.

The current thought and implementation leaders of computer science education – the USA and the UK – cannot quite match Switzerland's opportunity profile. They do not have the required combination of funds, national curriculum, and professional development capacity. Unfortunately, for Switzerland to reach this potential it will have to overcome two main obstacles:

1. CSER is not well aligned with Switzerland's Research Funding model. For instance, the human/machine interaction angle, common to most computer science education research, does not fit well with the SNSF model division categorization. CSE is not recognized as an area of concern and is perceived as vocational service, and not as a research challenge.

2. CSER Output in Switzerland is practically nonexistent. The causal connection between research funding and research output is hard to disentangle but the number of publications in the field of CSER in Switzerland is extremely low even when adjusting for the size of its population. Universities, including the ETH Zurich and EPF Lausanne as well as schools of education, woefully underperform in CSER compared to other nations, especially the USA and the UK.

Strategy

Computer science education research needs to be recognized as the basis for the digital revolution that needs to be supported by the SNSF. The leadership position of the USA in the digital revolution can, in large parts, be traced back to the support of CSER by the NSF. For many decades NSF has pioneered CSER through a number of dedicated CSER funding programs. These programs have contributed to basic research by advancing learning sciences but also by supporting practical concerns such as broadening participation in computer science through innovative technology experiences for students and teachers. Switzerland is wavering with respect to its investment into the digital revolution. Ideally, government funds considered for digital revolution should be channeled through the Swiss National Science Foundation as CSER focused research solicitations such as National Research Programs.

3.1 Introduction

3.1.1 Goal of the paper

Digital transformation is currently the topic with regard to our living and working environment. Digitalisation not only changes the way we live and work, but also how we interact with others. It will further introduce new ways of consuming and producing goods and services. We certainly are in a situation of radical change. However, what awaits us in the future is not clear. At the same time, all industries will be affected by the digital disruption, particularly health care, public administration, and education (Becker, 2015; Becker, 2016; World Economic Forum, January 2016).

Digital competences of leaders, employees, and citizens are key factors to successfully cope with this uncertain future (Becker & Knop, 2015; Johnson et al., 2016; Kienbaum Consultants International GmbH & Bundesverband Digitale Wirtschaft e.V., 2016; Studiengemeinschaft Darmstadt, 2016; Wachtler et al., 2016). But what exactly are digital competences? How can digital competences be operationalised and developed?

This paper thus focuses on digital competences. It will look at the status quo and identify relevant future directions. It is the aim of this paper to provide a solid orientation for educational policy makers, including the introduction of a digital competence framework. However, my paper cannot cover all aspects relevant to this complex topic. My intention is rather to identify the right questions to ask and to provide some orientation on how to move on to further investigate digital competences in a medium- to long-term perspective, and also to reveal possible "blind spots". The aim is to survey the multiple dimensions of this complex subject in order to outline a fundamental approach for tapping the potential of "digital competences for 2030".

3.1.2 Problem statement: New human-machine interaction

In terms of long-term future scenarios, two contrasting positions are argued for: There is either the danger of a digital revolution costing a lot of jobs; or one expects an evolutionary development with new jobs and a higher prosperity for society. Which scenario will prevail depends on decision makers in politics and the economy today, as Brynjolfsson and McAfee (2004) state.

Future university graduates are the decision makers of tomorrow. As change agents, they can act responsibly with regard to a digitalisation of the working environment and actively shape it, or they are driven as functionary elite by the developments. Management as a reflective discipline has to make decisions that are aligned with norms and moral concepts. The current situation of change offers the opportunity to ask fundamental questions: In what kind of a society do we want to live? What does the economy contribute? What kind of idea of mankind do we impose, when designing the future interaction of humans and machines? In this context, universities are challenged to prepare future leaders as decision makers.

Before I continue, it is important to first elaborate on what digitalisation stands for. According to Seufert and Vey (2016) digitalisation in its most comprehensive form comprises:

- The expansion of the Internet through a connection of things (Internet of Things);
- Processes and control systems that work mostly digitally;
- Big Data and elaborate predictive and prescriptive analytics;
- The growing use of artificial intelligence (AI) and digital assistants as a decision support;
- The discovery of hidden connections in the enormous data volume of the digital universe.

Due to digitalisation, significant changes in functions and behaviour on individual, organisational, and social levels can be detected.

In the public debate, substitution (i.e. the replacement of jobs) is the primary focus as the lead story of Der Spiegel in September 2016 shows: "Wie uns Computer und Roboter die Arbeit wegnehmen und welche Berufe morgen noch sicher sind"[36] (Der Spiegel, 2016). Marc Andreessen penned his famous "Why software is eating the world" essay in The Wall Street Journal five years ago. "Digital Disruption" emerged as a new term in recent years and has seen almost excessive use: No matter your industry, managers reimagine their business to avoid being the next local taxi company or hotel chain caught completely off guard by their equivalent of Uber or Airbnb. With the upcoming technologies (AI and robotics) knowledge work will dramatically change. One could rephrase Andreessen's quote: "Software is eating management."

While optimists talk about an economic miracle, opponents of digitalisation forecast the end of work. However, there is a danger that society focuses too much on short- and middle-term demands that emerge from economic pressures, and neglect long-term implications of the current technological developments.[37] The new challenge of human augmentation is more subtle and difficult to grasp. Although books such as Frank Pasquale's "The Black Box Society" and Eli Pariser's "The Filter Bubble" have gained a lot of attention, the issue seems to be neglected in the educational debate. Furthermore, although these writings help illuminate many of the challenges, they often fall short of supplying viable solutions. This paper intends to shed light on this "blind spot" and argues that human augmentation is the major challenge of the fourth industrial revolution.

3.1.3

Augmentation is the key challenge for society and education

Definition, forms of augmentation

Imagine the following situation:

You feel really bad physically and decide to visit the emergency service at a local hospital. When it is your turn, two physicians enter, an elderly physician on duty together with his youngish assistant. The elderly physician says he commands 30 years of experience, he will find out what is wrong with you. The youngish assistant says he works with a computer database which comprises the knowledge of 600 years of western medical practice.

Who would you rather turn to?

I admit that the example is not very realistic as in practice the elderly physician will also have the best computer equipment. So we as patients will not have to decide between the two options. However, the imagined situation demonstrates the developments in medical diagnoses and why we should come to terms with the changes in human-machine interaction.

In the healthcare system one person will generate 1 million gigabyte of health-related data during her or his lifetime – equivalent to about 300 million books (according to Karin Vey, IBM Research ThinkTank). One example of augmentation is interactive machine learning for health informatics. When do we need the human-in-the-loop (HITL)? Holzinger (2016) recently explored this question in his research paper. The following section is a quote from his research (abstract) and demonstrates how humans and machines interact with complementary competences:

> Machine learning (ML) is the fastest growing field in computer science, and health informatics is among the greatest challenges. The goal of ML is to develop algorithms which can learn and improve over time and can be used for predictions. Most ML researchers concentrate on automatic machine learning (aML), where great advances have been made, for example, in speech recognition, recommender systems, or autonomous vehicles. Automatic approaches greatly benefit from big data with many training sets. However, in the health domain, sometimes we are confronted with a small number of data sets or rare events,

36 English translation: "How computers and robots take away our work and which jobs will still be safe tomorrow."

37 This is sometimes referred to as Amara's law: "We tend to overestimate the effect of a technology in the short run and underestimate the effect in the long run."

where aML-approaches suffer of insufficient training samples. Here interactive machine learning (iML) may be of help, having its roots in reinforcement learning, preference learning, and active learning. The term iML is not yet well used, so we define it as "algorithms that can interact with agents and can optimize their learning behavior through these interactions, where the agents can also be human." This "human-in-the-loop" can be beneficial in solving computationally hard problems, e.g., subspace clustering, protein folding, or k-anonymization of health data, where human expertise can help to reduce an exponential search space through heuristic selection of samples. Therefore, what would otherwise be an NP-hard problem, reduces greatly in complexity through the input and the assistance of a human agent involved in the learning phase. (Holzinger, 2016, p. 119)

Decisions on all management levels increasingly have to be made in consideration of computer-based data analyses and one's own gut feeling. Decision makers have to learn in what cases algorithms can help them to detect distortions in their thinking and when intuition in form of condensed knowledge comes into play. It is about being able to design flexible decision processes, understanding the role of digital tools, and using them competently. A cognitive assistant equipped with AI can make statistically sound proposals on the basis of enormous data volumes. Nonetheless, these results are limited. The proposals refer only to a specific area which we specify for the machine and questions that we have trained with the system. In contrast, humans are able to make holistic evaluations of a situation. A decision maker has to know about the different competences and limitations of machines on the one hand, and humans on the other hand, and to be able to design adequate decision processes (cf. Figure 3.1).

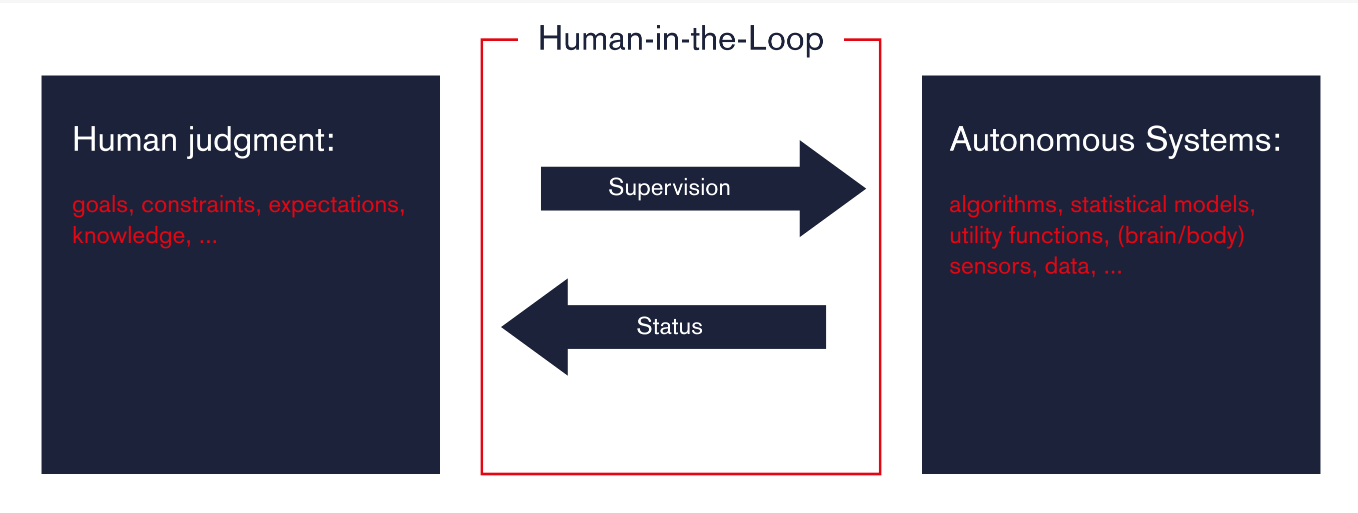


Figure 3.1. Human-in-the-loop (Rahwan, 2016)

Future forms of augmentation can already be observed today and investigated more deeply to elaborate future scenarios. As the American science fiction author William Gibson stated: "The future is already here — it's just not very evenly distributed." Table 3.1 below gives an overview of different forms and examples of human augmentation.

Form of Augmentation	Examples
Physical Augmentation: Advanced robotic devices that adapt to their environment or as integral parts of the human body ("Human 2.0")	– A paralysed man has made the first kick of the FIFA World Cup 2014 using a mind-controlled robotic exoskeleton. – Advanced robotic devices that are sufficiently small, safe and flexible to be inserted into human workflows, e.g. robotic surgery combines the advantages of small incisions with computer-assisted precision, enhanced vision and improved dexterity.
Cognitive Augmentation: Technologies that "learn" by observation and offload routine knowledge work to automated assistants	– Intelligent Personal Assistants: Cognitive assistants for all occupations are beginning to appear (IBM Watson, Apple Siri, Microsoft Cortana, Google Now, Amazon Echo, etc.) – Chess grand masters are getting younger and younger (Sergey Karjakin is only 12 years old). Why? They do not play against the computer, they play with the computer (to develop complementary competences).
Collaborative Augmentation: Software directly improves the ways humans coordinate work and co-create new products, learning together with the computer	– Learning-to-learn Competences: designing learning scenarios for self-regulated learning by using digital media – Providing instructional material, learning techniques
Emotional Augmentation: New human-machine interaction with social robots (which interact and communicate with humans by following social behaviours and rules attached to their role)	– In education & research: The social robot "NAO" serves as avatar for ill children in the classroom, therapy intervention with autistic children; NAO as a teaching assistant for refugee children learning German. – In business: Human robot "Pepper" for the retail industry, customer service, e.g. Nescafé Japan uses Pepper to sell coffee. – As training partners: "Showa Hanako 2" Dental Surgery Robot reacts like a human during dental treatment for training novices. – As team member: Chatbot "Nadia" as an employee of an Australian bank (voiced by Cate Blanchett). – As boss: Robots are allowed to communicate to someone that he or she is fired, it only needs a human being for the signature.

Table 3.1. Forms of augmentation: Examples for new human-machine interaction

With the digitalisation of knowledge work, augmentation is the real new challenge we have to face, and not substitution through automatisation (Autor, 2015). It is of considerable importance not to see work as a zero-sum game where machines gain an ever-increasing part (McAfee & Brynjolfsson, 2015). Many things that today cost a lot of time for a knowledge worker, like time-consuming research, can be done by computer systems in the future. Only in cooperation with the machine considerable improvement of quality is possible – collected knowledge will be newly, better and considerably more economically usable. This allows a considerably wider support of decisions. However, without the human to give the direction, machines provide only fragmented or irrelevant results.

"Human-in-the-loop (HITL)" and "Society-in-the-loop (SITL)"

With the development of algorithms and AI systems, HITL acquires a broader meaning in a new training field: the role of humans in the training of the machine. Today, many apps already learn from human behaviour in order to improve their ability to take over routine work (e.g. SMS systems, cognitive automation). Further fields of AI are for instance media diagnosis or robotic warfare. Such systems are more complex to develop. One of the main problems is that AI engineers are training the systems using huge amounts of data (Big Data) but usually are not domain experts. Therefore, any biases or errors in the data will create models reflecting those biases and errors. That is the reason why Ito (2016) demands a human lens for AI:

> Human-in-the-loop machine learning is work that is trying to create systems to either allow domain experts to do the training or at least be involved in the training by creating machines that learn through interactions with experts. At the heart of human-in-the-loop computation is the idea of building models not just from data, but also from the human perspective of the data. (Ito, 2016, para. 4)

Recently, Rahwan (2016), Professor at MIT Media Lab emphasised the need for a scaled-up version of HITL in his blog: a "Society-in-the-loop" approach for developing AI systems with wide societal implications. He asks what happens when

> an AI system does not serve a narrow, well-defined function, but a broad function with wide societal implications? Consider an AI algorithm that controls billions a [sic] self-driving cars; or a set of news filtering algorithms that influence the political beliefs and preferences of billions of citizens; or algorithms that mediate the allocation of resources and labor in an entire economy. (Rahwan, 2016, para. 5)

This is the reason why he demands a

> qualitative shift from HITL to society in the loop (SITL). … SITL is about embedding the judgment of society, as a whole, in the algorithmic governance of societal outcomes. In other words, SITL is more akin to the interaction between a government and a governed citizenry. … Similarly, SITL can be conceived as an attempt to embed the general will into an algorithmic social contract. (Rahwan, 2016, paras. 5–6)

Furthermore, Rahwan (2016) argues that we face a SITL gap, because

> we still lack mechanisms for articulating societal expectations (e.g. ethics, norms, legal principles) in ways that machines can understand. We also lack a comprehensive set of mechanisms for scrutinizing the behavior of governing algorithms against precise expectations. … Putting the society in the loop requires us to bridge the gap between the humanities and computing. (Rahwan, para. 14)

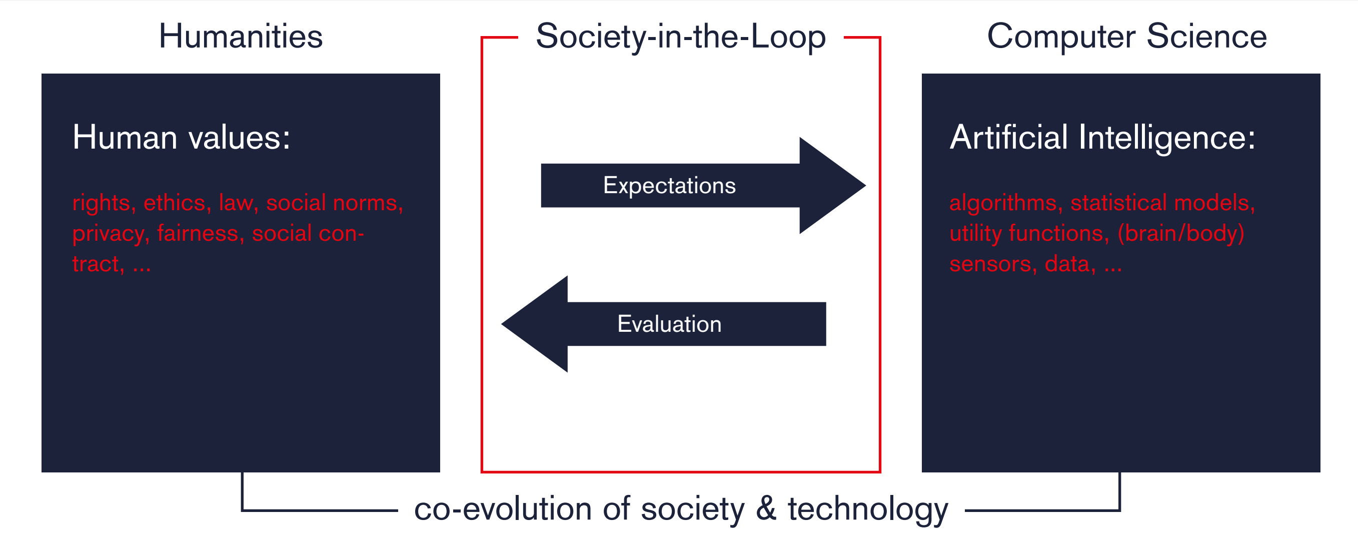


Figure 3.2. Society-in-the-loop (Rahwan, 2016)

Looking at Rahwan's (2016) model of SITL (as depicted in Figure 3.2), one might get the impression that in the current debate computer science gets all the attention. However, the co-evolution of society and technology is key. Both human values and AI are constantly co-evolving as Rahwan (2016, para. 15) illustrates: "Thus, the evolution of technical capability can irreversibly alter what society considers acceptable – think of how privacy norms have changed because of the utility provided by smart phones and the Internet." A main success factor will (therefore) be to develop adequate digital competences of a society.

Main thesis:
Leaders, educational policy makers, must understand the connection of human and computer and develop a vision for the successful partnership of human and machine – human values and AI –, with the aim to gain synergy through complementary competences.

3.2
Digital competences

3.2.1
Definition

The European Commission provides the following definition: Digital competence involves the confident and critical use of Information Society Technology (IST) for work, leisure and communication. It is underpinned by basic skills in ICT: the use of computers to retrieve, assess, store, produce, present and exchange information, and to communicate and participate in collaborative networks via the Internet. (European Commission, 2007, p. 7)

The EU framework of digital competences identifies the respective key components in five areas: information, communication, content creation, safety, and problem solving. To be competent, one needs instrumental skills, advanced skills and knowledge, and appropriate attitudes in applying these skills and knowledge – as shown in Figure 3.3 below.

This EU framework serves as a normative orientation in most European countries. Many EU countries have planned or already decided on a new national digital competence framework. There is no doubt that digital competences have become a core competence in the 21st century. There are similar developments in other countries outside the EU.

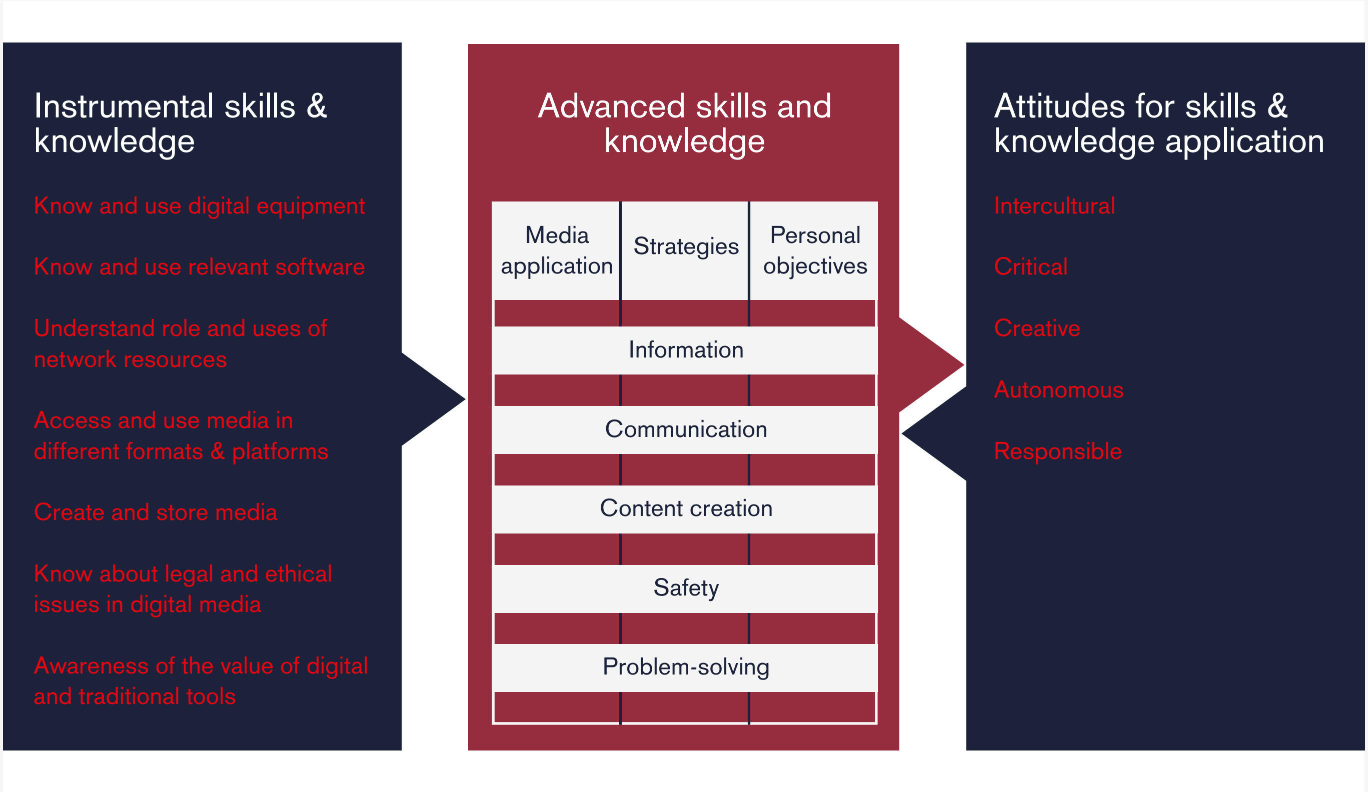


Figure 3.3. EU framework of digital competences, own representation based on Ferrari (2013) and Ala-Mutka (2011)

The World Economic Forum[38] defines the term "digital competences" as a "set of social, emotional and cognitive abilities that enable individuals to face the challenges and adapt to the demands of digital life." The DQ Institute[39] defines it as "having the necessary knowledge, skills and ability to adapt one's emotions and adjust one's behaviour to deal with the challenges and demands of the digital era." As part of it, the DQ Institute has identified eight aspects of digital citizenship and concludes that "these aspects are often overlooked as most people tend to focus on creativity and entrepreneurship".

3.2.2

Concepts of digital competences

Digital competence should play an essential part in a comprehensive education framework. Without a national digital education programme, command of and access to technology will be distributed unevenly and create new inequality – a digital divide on a new level. In most countries, digital competence is given transversal status in educational policy: Existing studies indicate that many national curricula have moved towards integrating transversal competences as a response to the number of social, economic, and cultural changes brought on by the rapid development of information and communications technology (ICT) (Voogt & Pelgrum, 2005).

Therefore, the main challenge seems not to be whether a national curriculum is needed, it is rather the question of how and to what extent transversal competences should be expressed in national and school curricula. Different education systems utilise different methods of integrating the teaching and learning of transversal competences into the curriculum. In general, there are three possible modes, which can be combined with each other:

- New specific subject: A subject with specific goals, new content and syllabi for formal teaching.
- Cross subject: Learning of transversal competences runs across, infiltrates and/or underpins all "vertical subjects", i.e. traditional school subjects.
- Extra-curricular: Learning of transversal competences is made part of school life and embedded purposefully in all types of non-classroom activities.

Many countries enrich their system and pursue a multiple mode (according to the study of Ananiadou & Claro, 2009, ICT-related content was predominantly added as new and separate subjects). Studies tend to support the incorporation of transversal competences across the curriculum due to the domain's complex and cross-disciplinary nature (Voogt & Roblin, 2012). Multiple countries have introduced policies and curricula aimed at cultivating transversal competences. Furthermore, in many countries a so called "spiral curriculum" from kindergarten to sec II (K-12) for integrating digital competences as transversal competences has been developed.

The main problem in coping with the dynamics of digital competences lies in the fast and ever evolving nature of the digital world, where proper educational government for developing digital competences is slow to catch up. Currently, Wales, for instance, explores a new approach with its digital competence framework: An interactive website informs about the framework, gives examples for learning tasks, and offers feedback mechanisms for the public (providing a dialogue-oriented platform).[40]

Generally, little attention is paid to which aspects are really new and why transversal competences are beneficial to students. This is problematic since many of the competences defined as transversal are not necessarily new nor completely absent in the existing curricula (e.g. problem solving, critical thinking, and collaboration). There is a strong need to better connect digital competence with these existing transversal competences. What is really new is to put these "old" transversal competences to a higher level in interaction with the machine (iML).

New concepts such as computational thinking as a problem-solving process have become popular, sometimes already titled the fourth cultural technique. According to Wing (2006, p. 33), computational thinking "represents a universally applicable attitude and skill set everyone, not just computer scientists, would be eager to learn and use."

38 https://www.weforum.org/agenda/2016/06/8-digital-skills-we-must-teach-our-children/

39 https://www.dqinstitute.org/what-is-dq/

40 http://learning.gov.wales/resources/browse-all/digital-competence-framework/?lang=en

3.2.3
Empirical studies

What do we know from empirical evidence, what is the status quo – how “digitally competent” are our students when they enter higher education? The following four studies and indices provide an insight about digital competences in Switzerland, across Europe, as well as the United States.

International Computer and Information Literacy Study (ICILS)

The ICILS is an important new contribution to our knowledge about digital competences of students and the integration of technology in teaching and learning. The study has been carried out by the International Association for the Evaluation of Educational Achievement (IEA), and supported by the European Commission’s Directorate General for Education and Culture. ICILS is the first ever internationally comparable study assessing students’ computer and information literacy (IL). 60,000 eight-graders in more than 3,300 schools from 21 education systems, including nine EU countries, were surveyed and assessed. As a result, ICILS 2013 as an educational monitoring study expands the perspective of previous international comparative educational assessment studies such as TIMSS (Trends in International Mathematics and Science Study), PISA (Programme for International Student Assessment), and IGLU (Internationale Grundschul-Lese-Untersuchung).

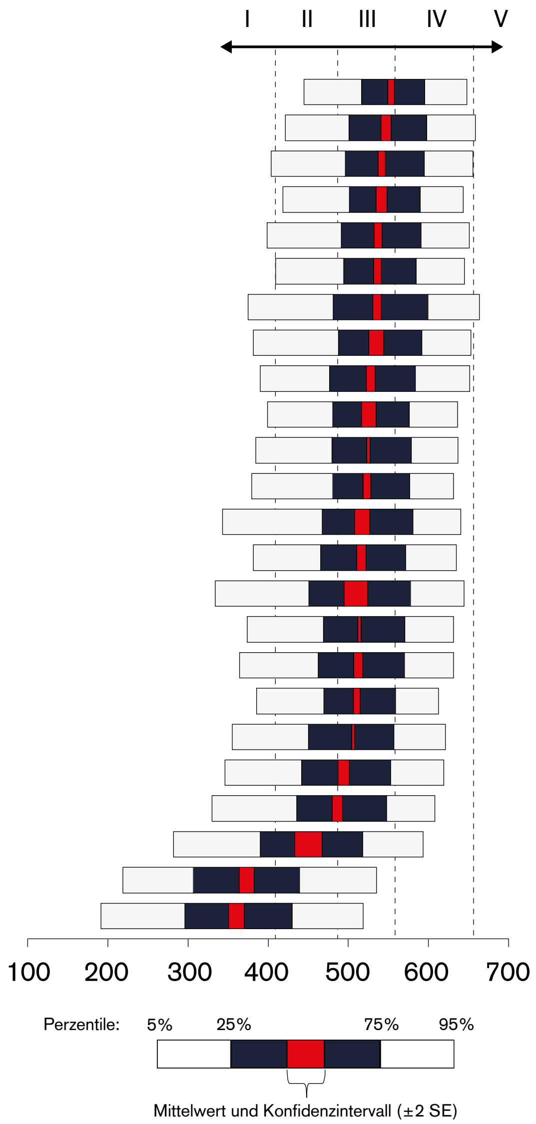
Figure 3.4 shows the results of the ICILS with the mean value (M) and the standard deviation (SD) of the reached points (maximum of 700 points) for each country. Swiss students did not score significantly above EU average. While only 2% of Swiss students reached the highest level of competence (V), almost 30% did not exceed the lowest competence level (I). Unfortunately, a detailed Swiss report is currently not publicly available,[41] however, data about Switzerland is included in the reports by Bos et al. (2014) and Eickelmann and Drossel (2016). Bos et al. (2014) conclude that the assumption under which students automatically become digitally competent by simply growing up in a world dominated by digital technologies is wrong. Students from countries with a national digital competence framework in education seem to score higher on average.

According to the ICILS website,[42] the next study will be carried out in 2018. This study will also report on the computational thinking domain, which is “understood as the process of working out exactly how computers can help us solve problems. This domain includes not only programming but also structuring and manipulating data sets.” Switzerland is currently not listed as a participating country, although such a participation would be highly desirable in order to obtain and have access to relevant educational data.

41 The initial report has been withdrawn due to a low participation ratio, although over 3,000 Swiss students participated.

42 http://www.iea.nl/icils

Teilnehmer	M	(SE)	SD	(SE)	
Tschechische Republik	553	(2.1)	62	(1.6)	▲
Kanada (O.)	*547*	*(3.2)*	*73*	*(2.2)*	▲
Australien	542	(2.3)	78	(1.6)	▲
[3] Dänemark	542	(3.5)	69	(2.0)	▲
Polen	537	(2.4)	77	(1.7)	▲
[1,2] Norwegen	537	(2.4)	72	(1.6)	▲
Republik Korea	536	(2.7)	89	(1.5)	▲
[3] Niederlande	535	(4.7)	82	(2.9)	▲
[2] *Kanada (N. & L.)*	*528*	*(2.8)*	*80*	*(2.3)*	■
[3] **Schweiz**	**526**	**(4.6)**	**72**	**(2.6)**	■
VG EU	525	(1.1)	77	(0.7)	■
Deutschland	523	(2.4)	78	(2.0)	■
Slowakische Republik	517	(4.6)	90	(3.3)	■
[2,5] Russische Föderation	516	(2.8)	77	(1.7)	■
[2,3] Hongkong	509	(7.4)	95	(4.8)	■
VG OECD	516	(0.9)	79	(0.6)	▼
Kroatien	512	(2.9)	82	(1.7)	▼
Slowenien	511	(2.2)	69	(1.2)	▼
Internat. Mittelwert	**500**	**(0.9)**	**81**	**(0.6)**	▼
Litauen	494	(3.6)	84	(2.6)	▼
Chile	487	(3.1)	86	(2.5)	▼
[3] *Argentinien (B. A.)*	*450*	*(8.6)*	*94*	*(4.0)*	▼
[5] Thailand	373	(4.7)	96	(2.6)	▼
Türkei	361	(5.0)	100	(3.0)	▼



▲ Teilnehmer, die signifikant über dem Mittelwert von Deutschland liegen ($p < .05$).

■ Kein signifikanter Unterschied zum Mittelwert von Deutschland.

▼ Teilnehmer, die signifikant unter dem Mittelwert von Deutschland liegen ($p < .05$).

Kursiv gesetzt sind die Benchmark-Teilnehmer.

[1] Die nationale Zielpopulation entspricht nicht der 8. Jahrgangsstufe.

[2] Die Gesamtausschlussquote liegt über 5%.

[3] Die Schüler- und Schulgesamtteilnahmequote liegt unter 75%.

[5] Abweichender Erhebungszeitraum.

Figure 3.4. Results of the ICILS 2013 (Bos et al., 2014). 500 points represent the international mean, I–V refers to level of competence (see Bos et al., 2014, for an explanation of competence levels)

Study “Information and social media competence” (University of St. Gallen)

Our own study “Information and social media competence” on the Lake Constance region (Seufert, Stanoevska, Lischeid & Ott, 2017) provides similar first results (434 students: 108 from Germany, 94 from Austria, 198 from Switzerland and 34 from Liechtenstein). A full-scale study with 2,000 students is planned and the results will be available at the end of 2017.

Measuring objective IL and self-assessed IL of digital natives in secondary school unveiled the discrepancy that most of the students evaluate themselves as competent, while the objective literacy is considerably lower – these results are alarming. The outcome of the study at hand is in line with the empirical evidence provided by other researchers concerning IL of digital natives: Although pupils are active users of the Internet, prior research has observed that pupils often do not have sufficient Internet skills. Most of them lack adequate web searching skills, as well as the ability to process and critically evaluate web information.

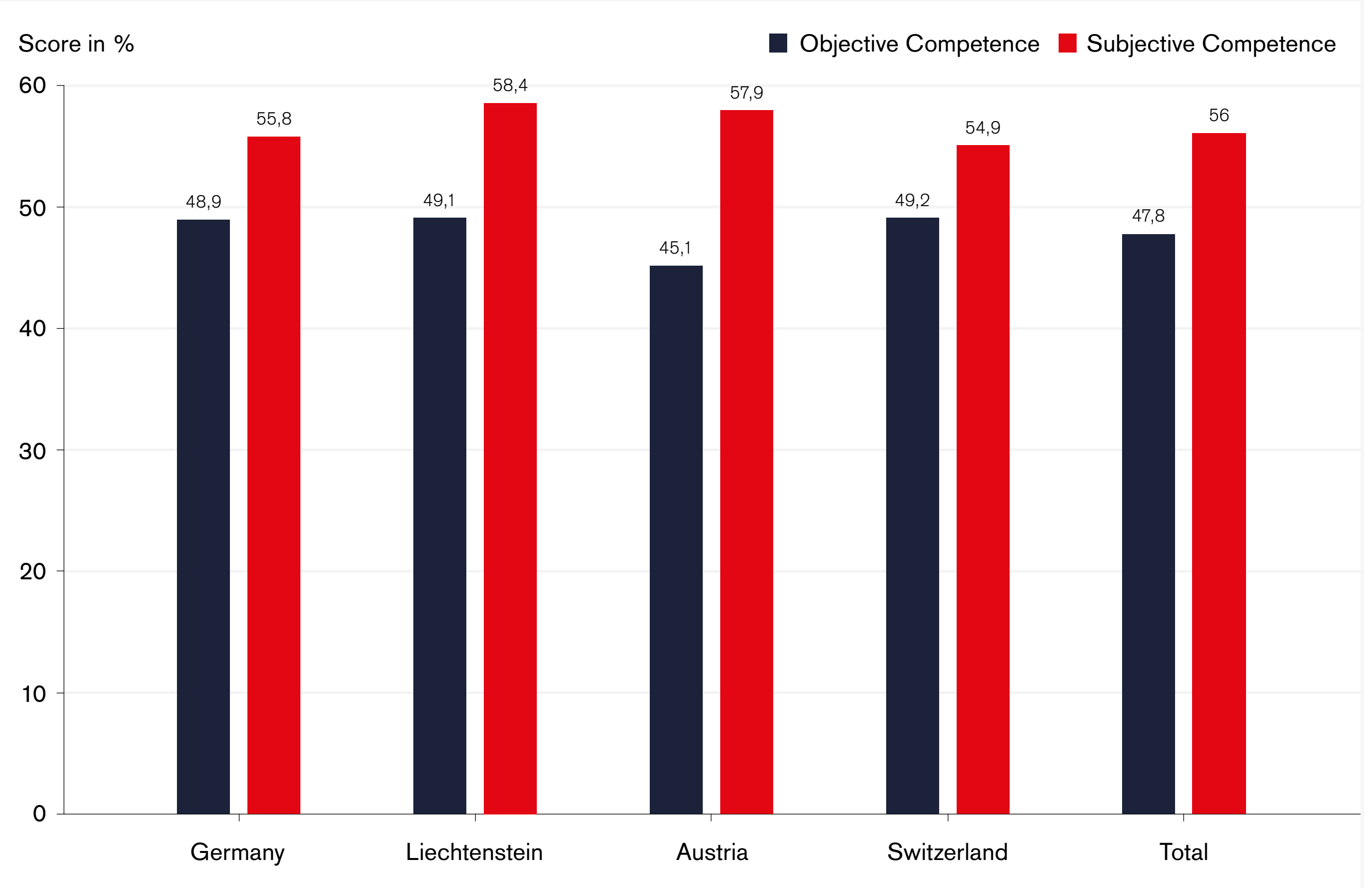


Figure 3.5. Information and social media competences at sec-II level (Seufert et al., 2017)

Study “Evaluating Information: The Cornerstone of Civic Online Reasoning” (Stanford University)

The Stanford History Education Group (2016) has analysed the civic online reasoning – “the ability to judge the credibility of information that floods young people’s smartphones, tablets, and computers.” The study administered 56 tasks to students across 12 states and collected responses from 7,804 students from middle school, high school, and college. The researchers described the information competence of the students with just one word – “bleak”. The authors published the results before the election of Donald Trump. In their conclusion they state: “we worry that democracy is threatened by the ease at which disinformation about civic issues is allowed to spread and flourish” (Stanford History Education Group, 2016, p. 5).

Digital Economy and Society Index (DESI)

The European Commission recently published the results of the 2017 DESI, a tool presenting the performance of the 28 member states in a wide range of areas: five dimensions of the digital economy and society, including human capital and digital skills in a country. The tool is a digital scoreboard providing a wide variety of visualisations of the data and with API access.

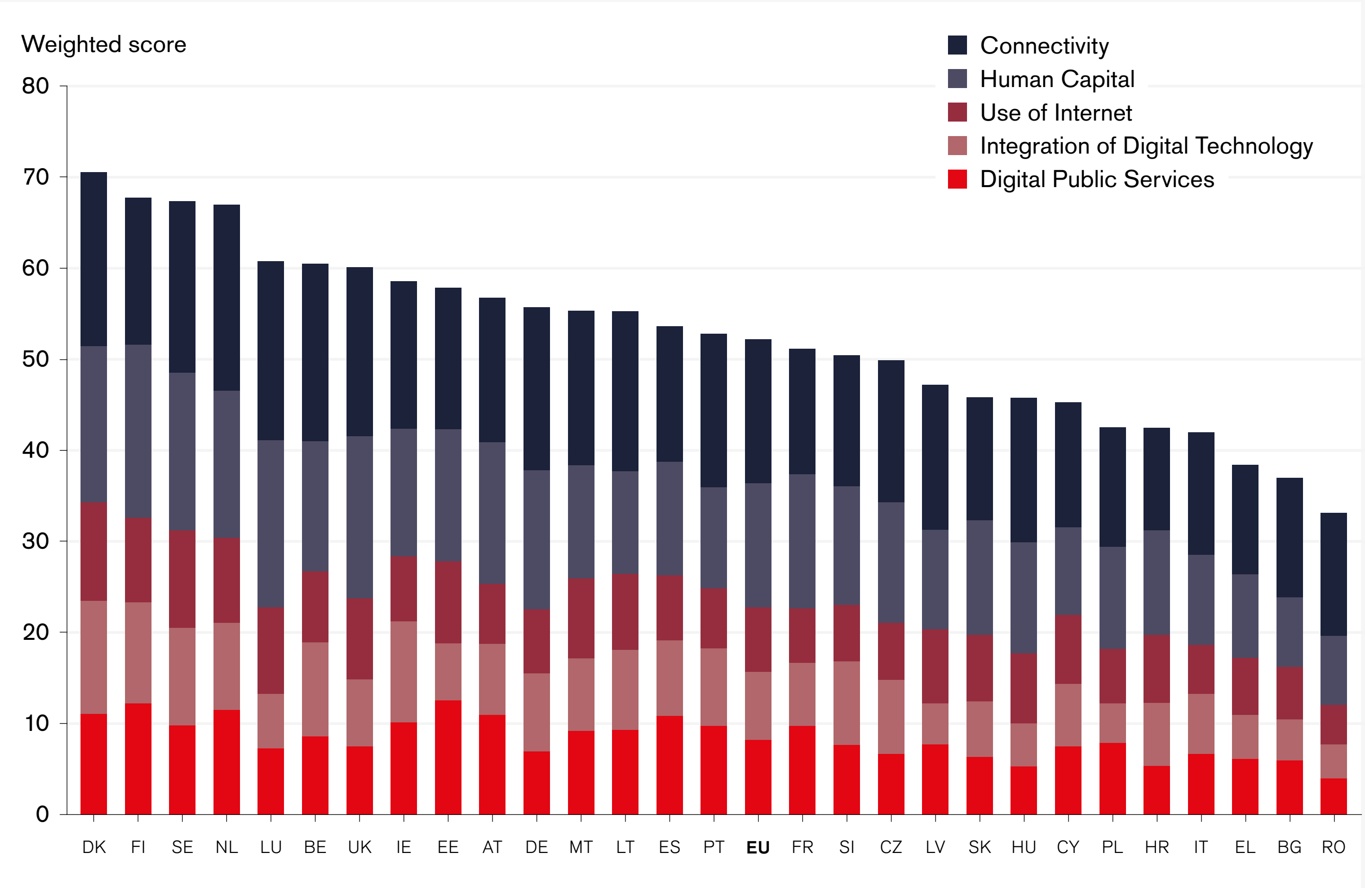


Figure 3.6. EU Digital Economy and Society Index 2017

Summary of the empirical findings

- Unravelling the digital native myth: Many "digital natives" are not digitally competent. Being born in a digital era is not a sufficient precondition for being able to use technologies in a critical, creative and informative way.

- There is a need to address gender gaps and assure a comprehensive approach to the development of digital competences in school. Additionally, it is necessary to examine how boys can be encouraged to develop the less technical aspects of digital competence to the same level as that of girls. However, girls need more support for their self-esteem, there is some empirical evidence that they underrate themselves (important for science, technology, engineering, and mathematics [STEM] subjects).

- For both genders, it is also important that the education system has a comprehensive approach to digital competences, stimulating the critical and communicative use of ICT as well as attracting young people to ICT-related careers.

- Information literacy (the fundament for "Civic Online Reasoning") is one of the most important digital literacies. It is alarming that "digital natives" have deficits particularly in this competence area. Never have we had so much information at our fingertips. Whether this will make us smarter and better informed or more ignorant and narrow-minded will depend on our awareness of this problem and our educational response to it.

- In terms of computer and information literacy, Swiss students do not exhibit above average competences in comparison to other EU countries. Furthermore, there seems to be some evidence that Swiss students have deficits particularly in information literacy. An appropriate evaluation of information, however, is central to civic online reasoning.

3.2.4
Outlook

Currently, we are facing the implications of the "Googleisierung" (Stark, Dörr & Aufenanger, 2014) in our society. As Lobo (2013, para. 21) states, the Internet is "eben kein Bildungsautomat, sondern, ohne ein epistemologisches Fundament des Nutzers, eine Halbwissenmaschine." The education system in its current state already exhibits numerous areas with an urgent need for action. But the digital revolution, including the economic impact of digital transformation, as well as the rapid developments in AI and cognitive computing systems put on additional time pressure. If the key challenge of augmentation remains a "blind spot", there is a certain danger that one to two generations might get lost and a digital divide will introduce additional societal challenges.

In order to successfully tackle the key challenge of augmentation and evade the establishment of a (new) digital divide, it is necessary to introduce a comprehensive and holistic framework which establishes digital competences in the national curricula. I will present such a framework in the subsequent Section 3.3.

3.3
A digital competence framework

3.3.1
Overview of the conceptual framework

A national digital competence framework for Switzerland does not yet exist. To some extent the “Lehrplan 21” harmonises the curriculum and integrates media education. It appears that the integration mode 1 – the introduction of a new specific subject – is being applied in the educational domain:

- Primary/Sec I: “Media and informatics” (Lehrplan 21) and
- Sec II: “Informatics” in middle schools[43]/Sec II is in discussion.

Digital competence does not appear and is not given transversal status in educational policy. Only the use of digital tools in other subjects is discussed and explored. However, the connection to main transversal competencies such as problem solving is not considered (as stated before, this is a common problem, not just in Switzerland). The proposed framework as shown in Figure 3.7 tries to give an orientation of the multifaceted dimensions of digital competences and will be explained in the following subsections.

Figure 3.7. Digital competence framework

43 https://www.nzz.ch/schweiz/anhoerung-zu-mittelschul-lehrplaenen-informatik-wird-pflichtfach-ld.1296091?mktcid=nled&mktcval=107_2017-5-23

Normative orientation and values

As stated in Section 3.11: The current situation of change offers the opportunity to ask fundamental questions: In what kind of a society do we want to live? What does the economy contribute? What kind of idea of human do we have to, for example, design the future interaction of human and machine?

The debate surrounding what actually constitutes quality education and learning in the 21st century is ongoing. There is a growing concern that education systems are focusing too much on the accumulation of academic "cognitive" skills at the expense of the more elusive and hard-to-measure "non-academic" skills and competences. Beyond knowledge, these abilities must be rooted in human values of integrity, respect, empathy, and prudence. These values enable the wise and responsible use of technology – an attribute which will mark the leaders of tomorrow.

Following Aristotle, technology goes beyond the material solution to include also the rationality that lends plausibility criteria to a particular technical method and determines the appropriateness of the chosen technical means with regard to the desired purposes. "Practical wisdom" as an old intellectual virtue of practical reasoning, is becoming modern again in a digital world – as a complement to machines (Schwartz & Sharpe, 2011). Practical wisdom requires a degree of self-awareness and self-reflection:

> Practical wisdom demands more than the skill to be perceptive about others. It also demands the capacity to perceive oneself – to assess what our own motives are, to admit our failures, to figure out what has worked or not and why. … Being able to criticize our own certainties is often a painful struggle, demanding some courage as we try to stand back and impartially judge ourselves and our own responsibility. (Schwartz & Sharpe 2011, p. 18)

A digital competence framework should include the discussion about practical wisdom and an appropriate value system necessary to incorporate the "Society-in-the-loop" concept (see Subsection 3.1.3). In a digital society, the overriding goal is personality development; digital literacy and citizenship are its relevant foundations.

Digital literacies: Basic understanding and use of technology

To be digitally literate needs a basic understanding of upcoming technologies. New content has to be integrated in school curricula. Examples for discovering new human-machine interaction could be:

- Basic understanding of programming;
- Basic understanding of the various approaches to AI;
- Basic understanding and knowledge of statistics;
- Basic understanding of natural language processing;
- Basic understanding of the psychology of perception and of user guidance;
- Basic understanding of encryption and data security.

Digital citizenship: Socioeconomic impact of technology

According to the digitalcitizenship.net, "Digital Citizenship is a concept which helps teachers, technology leaders and parents to understand what students/children/technology users should know to use technology appropriately. Digital Citizenship is more than just a teaching tool; it is a way to prepare students/technology users for a society full of technology. Digital citizenship is the norms of appropriate, responsible technology use."[44] The normative orientation for the responsible use of technologies faces the main problem of the "time lag" and "parallel universes" of teachers, parents and students. Today, with the technological advances, the worries are even greater. Ribble and Bailey (2005) already raised this issue:

> Sociologists have determined with every new technology there has been a lag between the time it is introduced and the point where it becomes mainstreamed into society (Krotz, 2003). During that time, society creates rules, policies, and procedures that will help users to understand the technology. The recent wave of digital technologies has left our society gasping for air. When we begin to understand one technology, another new one comes along. In the past, it has been the adults who have taken hold of the technology, come to grips with it, and then passed down the knowledge to the next generation. With the tsunami-like nature of new digital technologies, children are learning to use technology at the same time as the adults. This leads to misunderstandings and uncertainties of how technologies can or should be used. (Ribble & Bailey, 2005, p. 11)

44 http://www.digitalcitizenship.net/uploads/TeachingDC10.pdf

I propose to reframe the argument from the narrow concept of the digital divide to the concept of digital citizenship, or the capacity to participate in society online. What does it mean to be a digital citizen? Participation in society online requires regular access to information technology and the effective use of that technology. Digital citizens can be defined as those who use the Internet every day: Frequent use requires some regular means of access, some technical skill, and the educational competencies to perform tasks such as finding and using information in the web, and communicating with others.

Furthermore, digital competences have to be integrated into other subjects as well and combined with transversal competences.

Examples for the curriculum: Societal and economic impact of technology (as cross subject)

- Digital vs "analogue" society
- Interdependencies between humans and machines
- Change in self-perception (self-definition) of humans in the face of emerging technologies and robots
- Value of information and data: Commercialisation of IT services and data access
- Robots – are they the "better" workers?

Personality development in a digital society: Complementary core competences

In the last few decades, computers have posed a daunting challenge for us. In particular, in order to achieve better results, we had to learn how to adapt to the functioning of the machine. Now we are experiencing a radical change. The interaction with the system becomes increasingly natural. We can easily communicate with the systems – through our language and our gestures. Nevertheless, there are decisive differences in the communication with machines compared to the communication with humans. The relationship remains asymmetric. The dialogue is purely objective and specific in depth. A person would initiate a richer, more extensive exchange – for example, introduce more context, associations, and metaphors. Moreover, the dialogue between people includes three further levels: self-disclosure, relationship level, and appeal character.

For us humans, it will be important in the future to be able to distinguish between accessibility through language expression and the restrictions mentioned above with respect to communication levels. We will be able to interoperate with data in a new way, compensate for local data space, and navigate in hybrid worlds. For example, we will make decisions in groups in immersive data spaces. This in many ways new interaction with digital content requires new skills. AI challenges us to identify and develop our core competences. It is about raising our cognitive-emotional skills to a higher level. Highly developed skills, such as abstraction ability, generalisation, creativity, and empathy are increasingly in demand.

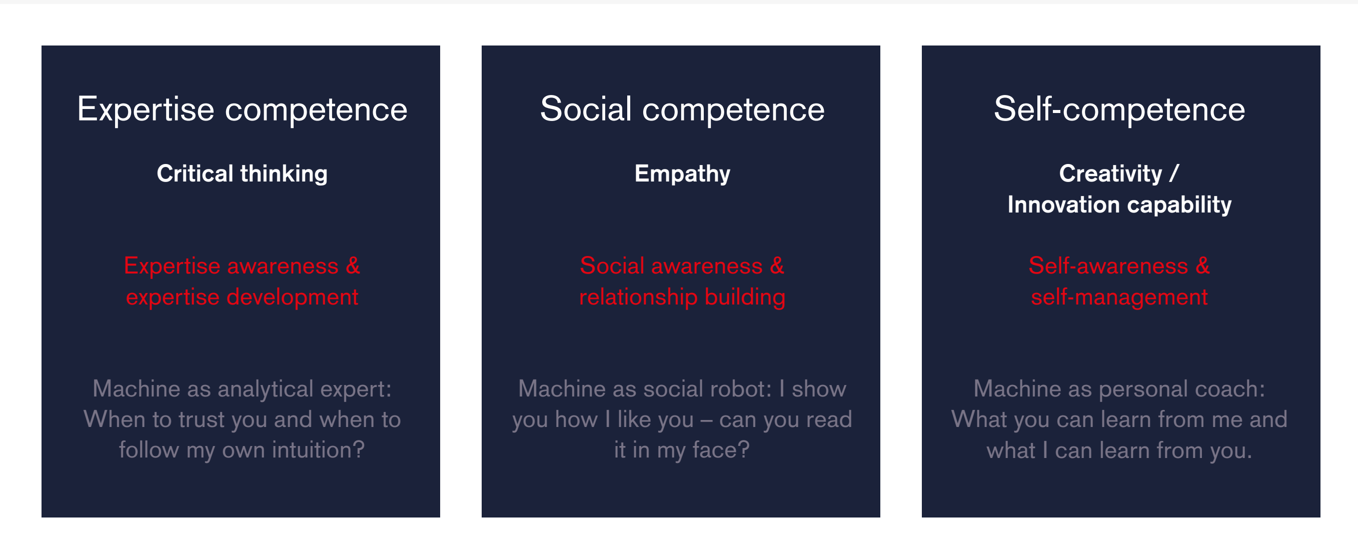


Figure 3.8. Complementary core competences of digital competences (as transversal competences)

Expertise competence: Core competence “critical thinking”

- In general: “New mind-sets and attitudes” in computational thinking
- Rethinking research: Finding the right information in huge amounts of data extremely efficiently – asking adequate questions, based on epistemological fundament
- Decision planning: Comprehensive presentation of alternatives and recommendations, with confidence levels and transparent sources, i.e., evidence-based!
- Discovery: Finding and identifying hidden connections, or recombining data from huge data spaces to create something new

Social competence: Core competence “empathy”

- The capacity to place oneself in another’s position. Empathy is seeing with the eyes of another, listening with the ears of another and feelings with the heart of another
- “New mind-set” through the application of design thinking (human-centred design) in interdisciplinary settings
- Social robots will change the perceived social awareness
- Moral competence in social robots (new questions, dilemmas)
- Potential to enhance empathy through the interaction with social robots

Self-competence: Core competence “creativity, innovation capability”

- Higher order learning competences
- Experimentation and reflection
- Lateral thinking, creative thinking, divergent thinking, playful thinking
- Dealing with uncertainty, risk taking, and rule breaking
- Deliberate practice in the active maintenance of superior domain-specific performance (in spite of general age-related decline)
- New learning strategies (e.g. iML, HITL)

3.3.2

Spiral curriculum: Integration into the curriculum

Vertical integration: From primary school, sec I to sec II

I propose to emphasise the importance of key competence development. This means that the core curricula build on key competence development, an approach that can be seen in many areas of the curricula. This approach is a holistic one and should occur through the study of individual subjects in order to reach the goal of personality development. The following ideas provide examples for such key competences.

At the primary school level:

- Digital literacy refers mainly to students’ capacity to increasingly source, interpret and produce texts in different formats, managing and reporting on information and becoming active readers. The ICT competence refers to more technical skills, stating the need for students to become familiar with and proficient in the operational logic of different media and platforms.
- Digital citizenship: Apart from digital etiquette, digital rights and responsibility, already starting with digital entrepreneurship: The ability to use digital media and technologies to solve global challenges or to create new opportunities (project-based learning appropriate for children at respective age level).
- Transversal competences: Already start with epistemological foundation (knowledge is not stable, asking adequate questions for search, sensitise for information evaluation).

At the secondary level I:

- Multi-literacy skills are deepened and developed further with the aim of encouraging students to engage with the material, to improve communication and to produce information across different formats.
- Digital citizenship: digital access, digital communication, digital safety (security)
- Transversal core competences: easy programming, problem solving, data and computational thinking, critical and innovative thinking, extra-curricular activities (e.g. digital entrepreneurship – start with a problem space and solve it by using design thinking mindset and process)

At the secondary level II:

- At this level, ICT competence begins to bridge students' school life with the professional world, supporting autonomous learning and inviting skills learned from outside school into the classroom. Students are asked to understand the role of ICT in society and practise transversal use of ICT across different subject matter.
- New subjects "Informatics": basic understanding of technologies (e.g. difference between automated and iML)
- Digital citizenship: digital law, digital commerce, digital health and welfare
- Transversal core competences with focus on new human-machine interaction: data and computational thinking: problem solving, data and IL.

To sum up:
As curricula are remade to suit the needs of future students, they should adopt a number of shared values also expressed within the framework such as e.g. promoting a learner-centred discourse, developing a flexible balance between the individual student and the learning community, and a transversal application of a range of skills including digital competences. A key digital competence is information literacy. The core curricula should build on key competence development with the overall goal of personality development in a digital society based on shared values. An example of such a curriculum can be found in the Appendix.

Horizontal integration: Specialities in vocational education

Vocational education is heavily influenced by the digital transformation many companies and organisations (e.g. smart government) are faced with. According to the EU framework, innovation is considered as the highest level of digital competence proficiency. The DigEuLit three-level model distinguishes three levels (Ferrari, 2012): Level I includes the basic skills, competences and approaches that are considered to be the foundation for digital competence. Level II refers to the application of digital competence within specific professional or domain contexts, where digital competence is applied to practice. Level III is about innovation and creativity, and the ability to stimulate significant change within the professional or knowledge domain.

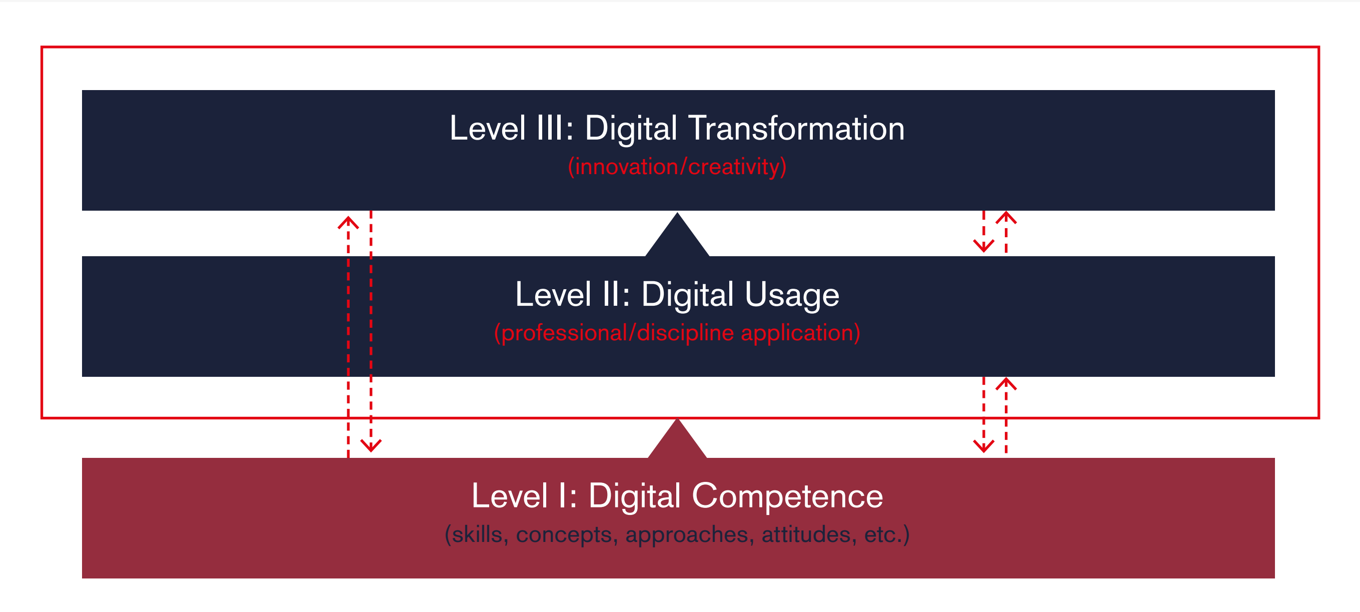


Figure 3.9. Digital competence, usage in a profession/discipline and digital transformation (Ferrari, 2012; Martin & Grudziecki, 2006)

For organisations, digital competences would embrace the competent use of digital tools and the functioning in the digital world in order to be successful in the course of digital transformation, as depicted in Figure 3.10 below.

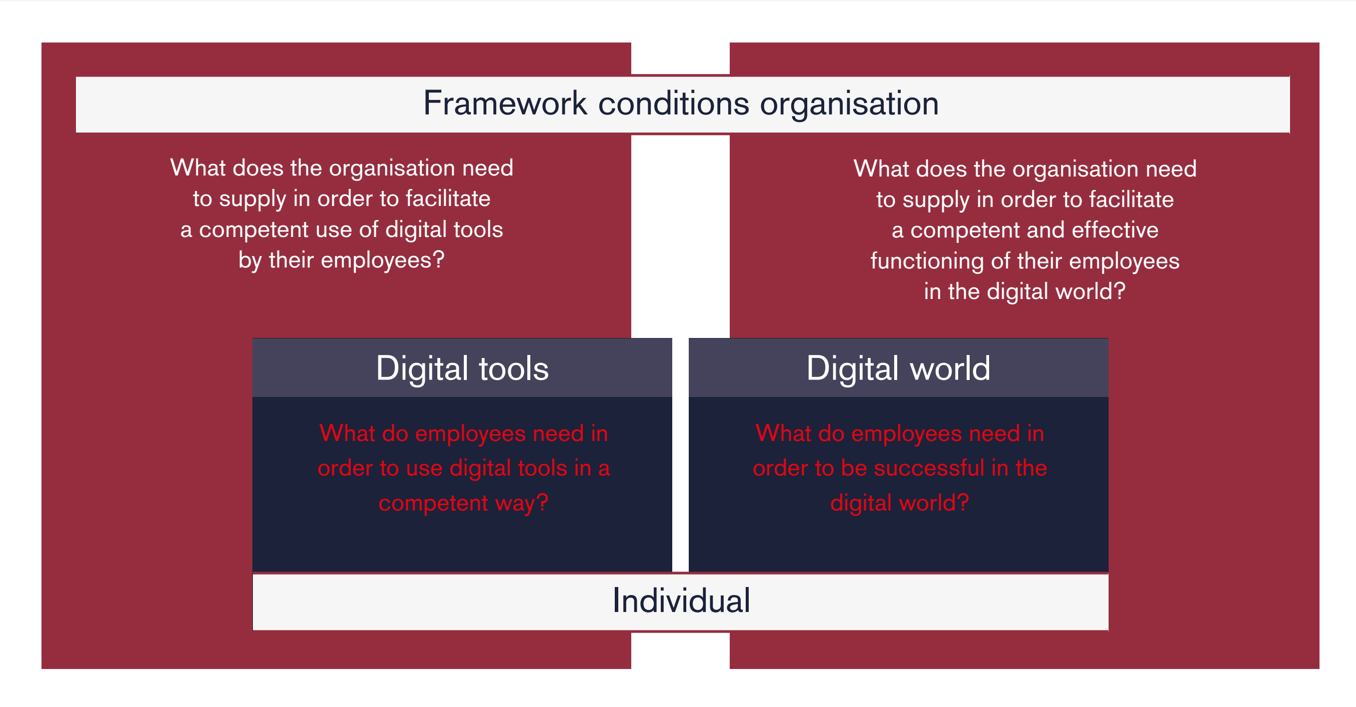


Figure 3.10. Digital competences at organisational level (in the context of digital transformation)

In vocational schools students should get prepared as soon as possible with respect to changes due to the digital transformation. Such changes may be driven by technologies such as the Internet of Things, cloud computing, Big Data, augmented and virtual reality, and AI and ML. A conceptual overview of new requirements in competences due to the digital transformation can be found in the Appendix.

Examples for the integration of digital competences as transversal competences are given in the following Table 3.2 (based on the example of vocational education and training in the commercial domain):

Existing subjects	Measures to develop a "digitally enhanced curriculum"
Economy and society	– Developing a modular concept map of thematic areas – Integrating cases in the digital context and emphasising the necessity of life-long learning, self-regulated learning as core competences – Developing/curating digital content to explain new technological advances such as Big Data for example, as well as the economic, social, ethical, legal implications for economy and society – Developing problem-based learning scenarios for current debate and implications on the commercial sector
Deepening and networking	– Developing problem-based learning scenarios for current debate and implications on the commercial sector (first focus: banks, insurance sector) – Developing interdisciplinary project work on current issues in the context of digitalisation
New subject: method-, self-, and social competences	– Learning-to-learn Competences: designing learning scenarios for selfregulated learning by using digital media – Providing instructional material, learning techniques
Do-it-yourself (DIY) learning labs	– Open space for the collaboration of students, with other learning locations – Fablabs and Marker Spaces for experimentation – e.g. developing massive open online courses (MOOCs) as team-work in specialised areas – Bridging formal and informal learning at home, school, work

Table 3.2. Examples for a "digitally enhanced curriculum" in vocational and professional education and training

Figure 3.11 presents a seamless learning and double T-Shape model as a possible framework for how a curriculum in an agile mode could be structured and developed.

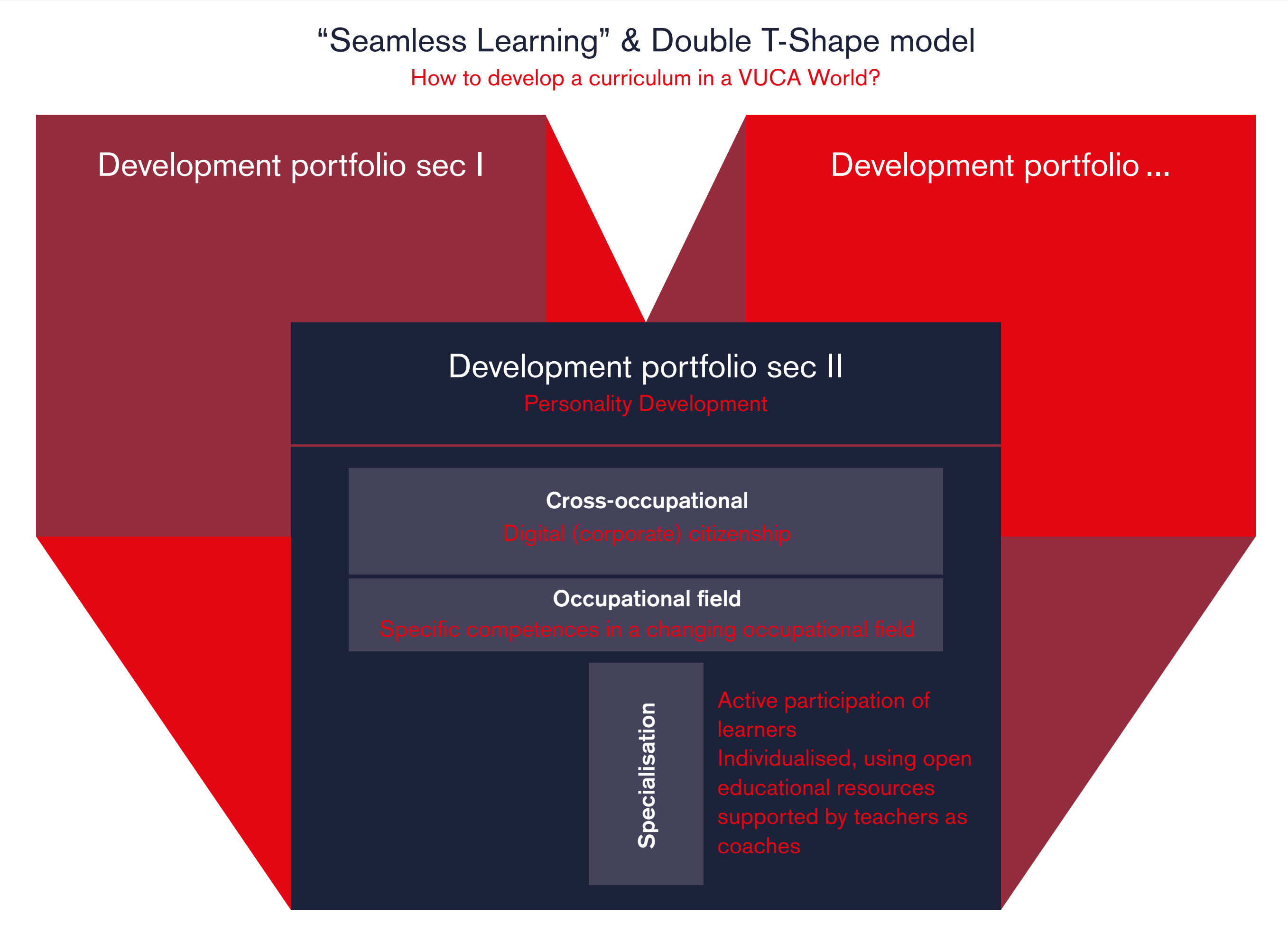


Figure 3.11. Curriculum development in vocational and professional education and training. VUCA stands for: volatility, uncertainty, complexity, and ambiguity

Horizontal integration: Specialities in higher education

The university education report 2020 of the Stifterverband für die Deutsche Wissenschaft e.V. (2016) argues for the development of digital competences as part of professional knowledge and career-oriented skills, as well as part of the personality development. However, the current discussion mainly focuses on professional and work-related skills. It is insufficient to integrate digital competences into existing study programmes purely as hard skills. Such a viewpoint provides a very technical and minimalist focus. This focus only explains how something works better. The focus should rather be on how the future of the digital world can create a work environment that is beneficial to people. A humanist educational idea is even more important than before. The most important goal for managers should be personality formation. Executives also need to understand some of the technical skills, but more important, they need to be able to solve problems, to act responsibly, and to develop their individual personalities. This type of leadership is needed.

As a result of the digitalisation, during the last few decades, creativity and empathy have been devalued (humans are underrated, Colvin, 2015). But they will be decisive for the success of tomorrow's leadership, e.g. if you want to ask the right questions or to create future designs and to make decisions responsibly.

Only this kind of person can transform the various tensions of a complex world into creative solutions. The challenge for future leaders is, on the one hand, to work on their own personality and competency formation and, on the other hand, to ensure that the entire system is developed further and that learning is possible at various levels in the organisation. Learning in the organisation becomes the top priority.

Further examples for the integration of digital competences as transversal competence are given in Table 3.3 below.

Mode	Measures to develop a "digitally enhanced curriculum"
Integration into existing subjects and programmes	– Developing a modular concept map of thematic areas as transversal competences – Developing problem-based learning scenarios for current debate and implications on decision making – "Human-in-the-loop" and "Society-in-the-loop"
Interdisciplinary project-/lab-based learning	– Developing problem-based learning scenarios for current debate and implications on the sector (e.g. health, financial sector, etc.) or on society – Digital entrepreneurship projects: The ability to use digital media and technologies to solve global challenges (e.g., climate, sustainability) or to create new opportunities – Developing interdisciplinary project work on current issues in the context of digitalisation: learning and research in Open Innovation Labs
New subjects: digital literacy skills for researchers	– Developing meta-competences for the reflection on textual norms and their interaction based on media conditions: information literacy, statistical literacy, critical thinking on research results – Providing instructional material, learning techniques for researchers
DIY learning labs	– Open space for the collaboration of students, with partners, encouraging students in extracurricular activities – Fablabs and Makerspaces for design and collaboration spaces – e.g. providing MOOCs for other students to learn digital skills, elaborating new research methods with Big Data, etc.

Table 3.3. Examples for a "digitally enhanced curriculum" in higher education

3.3.3

Constraints, limitations, and issues

The pedagogical use of digital media in schools remains constrained. As empirical studies show (e.g. ICILS 2013), dynamic and interactive pedagogical practices are not widespread in most countries and many teachers lack confidence and are sceptical about the potential of ICT to support student collaboration. A digital competence framework with transversal status in educational policy is missing. This can be regarded as a barrier. This is why discussions are progressively heading towards the development of competence frameworks not only for learners but also for educators.

The main challenge for educators, today, is to move beyond thinking of IT as a tool, or IT-enabled education platforms. Instead, they need to think about how to nurture students' ability and confidence to excel both online and offline in a world where digital media is ubiquitous. Due to their growing importance for companies and thus the commercial part of the training, vocational schools are coming under increasing pressure to address the implications of digital media for education and training. In this area, vocational schools are facing a permanent and extremely differentiated need to adapt, which is not seen in this scope or diversity in any other kind of school.

Common teaching practices are seen as a central barrier to innovation. This is because whether or not media enter the classroom depends not only on the technical prerequisites, but also on the skills and the willingness of the individual teachers to try out new forms of teaching. So far, however, school routine has been dominated by traditional forms of teaching, in which tutorials, individual and group work, and lectures are predominant. New teaching concepts, such as technology-supported, problem- or project-based forms of learning featuring shared digital notebooks or weblogs can only be integrated into such models to a limited extent.

The challenge for educational institutions consists in the appropriate use of ambidexterity and thus finding a balance between exploration of new opportunities and exploitation of existing competences. This organisational ambidexterity is often considered as a capacity or skill in itself. There is a need to communicate good examples and scale up good practices on active teaching practices and the collaborative use of ICT. The key question is how educational policy makers, leaders, and school principals can cope with potential tensions inherent in this ambidexterity and find a balance while managing this process of change.

Finally, the usage of Big Data in education (e.g. in learning analytics) also raises issues with regard to privacy, ethics, and norms. The following, non-exhaustive list highlights some of them:

Privacy:
- What data are generated by closely monitoring students' activities and who has access to these in what manner?
- Is the analysis in accordance with privacy arrangements and are the students properly informed?
- Is anonymity (hiding of student names) required for effective self-assessment?
- What are the data security issues when used as part of the grading?

Ethics:
- What are the dangers of abuse/misguided use of the data?
- If the focus is only on extrinsic motivation, then intrinsic motivation could be downsized – how to deal with the trade-off?
- "Big nudging" problems: not improving decision but manipulating – how to avoid data manipulation?
- What are the dangers of abuse/misguided use of a data-driven rule system?
- Is the risk for misinterpreting data hindering the scaffolding process by teachers?
- Is there a risk that students guided by adaptive learning systems (prediction) will develop fewer metacognitive abilities regarding monitoring and planning their own learning?

Norms:
- Are there legal data protection or intellectual property rights issues related to this kind of use of student data?
- Is social comparison inducing motivation or demotivation in students in the first semester?
- Course gamification could be merely misused by masking the terms, for example, by labelling assignments as quests and scores as experience points, without contributing to the students' learning goals.
- Problems may be caused by poor models or "over-fitting" parameter in predication learning models: sensitivity, spurious correlations, meaningless patterns, noise and classification errors (all very common problems in Big Data analytics).

3.4
Conclusions for educational policy makers

3.4.1
Raising awareness

Conclusion 1:
Broad information should focus on the major, new challenge of the fourth industrial revolution in order to uncover a possible blind spot:
Leaders, educational policy makers, have to develop a vision for the successful partnership of human and machine, with the aim to win synergy through complementary competences.

Digital transformation is not just a hype that will be over in 1–2 years. We are at the beginning of a new cognitive era. Augmentation, the human-in-the-loop and the scaled-up version of society-in-the-loop, is the key challenge of the fourth industrial revolution. Little attention has been given so far to the fact that digital competences are transversal competences.

More emphasis should be given to the use of ICT that supports active teaching practices: Innovative teaching and learning for all through new technologies and open educational resources reforms and initiatives to identify effective models for policy and institutional reform which foster systemic and sustainable change. There is a need to communicate good examples and scale up good practices of active teaching practices and the collaborative use of ICT. It should be emphasised that it is not only necessary to simply use digital tools; it is even more important to combine new digital learning forms with new competences: digital literacy and digital citizenship. However, there is a danger that the digital transformation in schools neglects future scenarios of digital competences in a broader sense ("blind spot"). There is a risk that even educated teachers are overwhelmed by the intensive and fast moving technological, social, and economic developments.

3.4.2
Curriculum development

Conclusion 2:
A national digital competence framework as a spiral curriculum with transversal educational policy status should be developed.

This framework could explicitly describe the emphasis on "digital competences 2030" across educational levels and the multiple contexts associated to their assessment. Four steps are typically recommended:

1. An operational definition for each of the digital competences is required so as to determine what should be expected from students at different age levels in terms of knowledge, skills, and attitudes. Such an operational definition can contribute to the development of a pedagogical continuum ("spiral curriculum") for planning and assessing the learning of digital competences across age levels and subjects.

2. The connections between core subjects and digital competences should be clearly identified. The introduction of interdisciplinary themes, to be addressed within and across subjects, could contribute to the strengthening of these connections. Moreover, the interdisciplinary themes are dynamic and in continuous change, since they must reflect contemporary societal issues.

3. To assure learning about and learning with digital media, the digital competencies should be embedded within and across other transversal competences and core subjects.

4. The role of formal and informal education contexts in supporting the acquisition of digital competences needs to be acknowledged and taken into account. Strategies to closely link what is learned in and outside school should be developed.

3.4.3

Formative assessments, integrated assessment systems and graduation portfolio systems

Conclusion 3:
New ways of assessment and measurement of digital competences are needed. Enhanced formative assessments (based on national assessment banks) need to be integrated into the assessment systems. In general, the grading system in education needs a dramatic change from standardised testing to graduation portfolio systems.

The development of national frameworks should address strategies to support and regulate its implementation and the necessary assessments.

— Current assessment models, which are mostly focused on the measurement of discrete knowledge, fail to assess 21st century competences and call for new assessments grounded in authentic and complex tasks. There is the need to move towards formative assessment, regarding it as a powerful way to make students' learning visible while at the same time providing feedback that can contribute to the capacity building of both teachers and students. An example is the CBAL (Cognitively Based Assessment of, for, and as Learning, Bennett, 2010) concept for an integrated assessment system. Furthermore, automated scoring systems of open-ended items (based on AI) will probably be available in the next five years. An integrated assessment system combined with a graduation portfolio system (as applied in Singapore,[45] for example) provides a holistic view of Big Data and learning analytics in education.

— As the trend goes from programming computers to programming people (algorithms, in education: prediction models for adaptive learning), there is the danger of losing a central value in our society: self-determination. Therefore, there is a need to support informational self-determination and participation and to promote responsible behaviour of citizens in the digital world through digital literacy.

— Recent discussions around the topic of Big Data in education revolve heavily around the potential of learning analytics to increase the efficiency and effectiveness of educational processes and the ability to identify and support students at risk to reduce drop-out rates (i.e. prediction). While prediction through learning analytics is in focus, reflection on learning is neglected. Reflection refers to critical self-evaluation on the basis of own datasets created in the process of learning or (in the case of teachers/facilitators) supporting learning and datasets created by others (e.g., a teacher reflecting on his or her own teaching style based on datasets generated by the students) (Greller & Drachsler, 2012).

3.4.4

Enabling DIY learning in educational institutions

Conclusion 4:
DIY learning should be encouraged in primary, secondary, and higher education institutions. A new mindset of creativity, innovation, and self-organisation (sharing culture) should be actively fostered in order to promote school and organisational development.

Evidently, there is a need to deeply and sustainably transform teaching and learning practice in the primary and secondary schools as well as in institutions of higher education. In addition, scalability guidelines to foster the development of key competences need to be provided. In this respect, research in educational change (Hargreaves & Shirley, 2009) emphasises that this can be achieved only by involving teachers and students in the decision making process and anchoring new practices in the most promising aspects of teachers' professional knowledge.

Therefore, educational policy makers should encourage and provide the conditions necessary for the development of an effective and sustainable way to support change through transversal, dynamic and collaborative sites of DIY learning (e.g. DIY labs). Young people's efforts to create and disseminate digital media have been associated with the growing DIY movement, giving educators and students the opportunity to create, share and learn in collaboration.

45 Singapore (highest student scores for reading, maths, and science in PISA 2015 survey), has dramatically shifted its graduation system: from standardised testing to portfolio systems. In order to graduate, students need to complete scientific investigation, literary analysis, social science research, and mathematical application, show proficiency in a world language, and finally carry out artistic performance. Renowned scientists like Prof. Darling-Hammond (2015) at Stanford University argue that the changed graduation system (the so called "Graduation Portfolio System") is one of the most important success factors of Singapore's educational system.

3.4.5

Capacity building: Digital competences of teachers

Conclusion 5:
One of the key success factors are school teachers. A major initiative for the competence development of teachers is needed. The conceptualisation and design of suitable education training measures for teachers require a systematic approach to the professional development of teachers.

Teachers addressing new digital skills such as the competent handling of online information are often entering uncharted territory in their respective fields. In this context, teachers are increasingly demanding the inclusion of media-specific qualification goals. The main challenge for educators is to move beyond thinking of IT as a tool and IT-enabled education platforms. Instead, they need to think about how to nurture students' ability and confidence to excel both online and offline in a world where digital media are ubiquitous. However, what competences teachers need to acquire remains rather vague and the discussion is mostly limited to the use and operation of computer applications and digital content media. Furthermore, it is obvious that formal seminars, such as one-day training workshops on how to use ICT, are not sufficient and effective in developing teachers' digital competences.

There is a need to encourage not just teachers' digital competences but also to encourage innovation and digital competences among institutional structures, institutions, and administrators. Policy action in key areas which guide educational practice, such as inclusion of digital material and activities in curricula design or allowing and encouraging digital assessment forms, could have a major impact.

Common teacher training practices in themselves represent a major issue and a reason why digital media teaching skills of teachers so far have been developed to a limited extent only. Like their students, most teachers informally learn how to use digital media. Teachers often simply do not have the time to attend a course or to work on a self-paced learning programme (Weiss, 2012, p. 3). School-based training courses that are tailored to the needs of a school are very widespread. However, some research studies show that even formally organised school-based events have a limited impact (e.g. Jurasaite-Harbison, 2009). Therefore, the international research literature on the education and training of teachers increasingly focuses on workplace-integrated learning and informal learning. One key finding is that formal and informal learning should be more closely interlinked for the skills development of teachers. A promising approach in particular would appear to be the search for interfaces between learning in formal and informal contexts.

Developing competences related to the use of digital media in teaching and learning therefore requires considerable efforts in vocational training and other schools. It will not be sufficient to set up a blended learning course as a one-time event. Successful support initiatives for the competence development of teachers, on the contrary, will have to be (1) rooted in their particular context and simultaneously (2) embedded in innovation strategies and quality development processes in their respective schools. In other words, curriculum development, staff training, and school development need to be aligned and coordinated in order to bring about real education reform. The development of a school culture in which students and teachers alike attach great importance to learning together and from each other is of central importance.

3.4.6

Research in the field of digital competences

Conclusion 6:
Digital competences at an organisational level need further investigation: Closing the "Society-in-the-loop" gap and learning analytics or academic analytics are examples of the new research field "digital competences at organisational level".

Interdisciplinary research for addressing the SITL gap:
An increasing number of researchers from both the humanities and computer science have recognised the SITL gap and are undertaking concerted efforts to bridge it. According to Rahwan (2016, para. 16) there is a need for new methods to research: "These include novel methods for quantifying algorithmic discrimination, approaches to quantify bias in news filtering algorithms, surveys that elicit the public's moral expectations from machines, means for specifying acceptable privacy-utility tradeoffs, and so on." Ito (2016) further elaborates that there

> would need to be a way for the public to test and audit the values and behaviour of the machines. … How machines will take input from and be audited and controlled by the public, may be one of the most important areas that need to be developed in order to deploy AI in decision making that might save lives and advance justice. This will most likely require making the tools of machine learning available to everyone, have a very open and inclusive dialog and redistribute the power that will come from advances in AI, not just figure out ways to train it to appear ethical. (Ito, 2016, paras. 8–9)

Learning analytics or academic analytics for educational institutions:
As the integrated assessment system (for professional development as well as for educational policy makers regarding the effectiveness of education) showed there are new fields for research. The terms "learning analytics" or "academic analytics" in higher education address the issue. Analytics can be a powerful tool for educational leaders and policy makers, but analytics can also increase existing value conflicts and introduce new ones. Greller and Drachsler (2012) propose that government agencies may collect cross-institutional data to assess the requirements of higher education institutes (HEI) and their constituencies.

3.5
Summary

Currently, we are facing the implications of the "Googleisierung" (Stark, Dörr & Aufenanger, 2014) on our society. Switzerland seems to be in the middle field regarding students' computer and information competences in comparison to other EU countries. Furthermore, there is evidence that Swiss students have deficits particularly in information literacy, but the appropriate evaluation of information is already today a central fundament for civic online reasoning. "Human-in-the-loop" and "Society-in-the-loop" demand for higher-order digital competences including competences complementary to those of machines in the future.

Main statement:
Leaders, educational policy makers, must understand the connection of human and computer and develop a vision for the successful partnership of human and machine – human values and AI –, with the aim to gain synergy through complementary competences.

Conclusion 1:
Broad information should focus on the major, new challenge of the fourth industrial revolution in order to uncover the possible blind spot of augmentation, which might lead to the neglect of complementary competences and hamper a new partnership of human and machine. Switzerland should participate in the next international ICILS study in 2018 in order to obtain and have access to relevant educational data (measurement of information literacy at the secondary l level).

Conclusion 2:
A national digital competence framework as a spiral curriculum with transversal educational policy status should be developed. It is recommended to distinguish between the levels of personality development in a digital society, digital citizenship and digital literacies.

Conclusion 3:
New ways of assessment and measurement of digital competences are needed. Enhanced formative assessments (based on national assessment banks) need to be integrated into the assessment systems.

Conclusion 4:
Do-it-yourself learning (e.g. Fablabs, Makerspaces, etc.) should be encouraged in primary, secondary and higher education institutions. A new mindset of creativity, innovation and self-organisation (sharing culture, co-creation concepts) should be actively encouraged in order to foster individualised learning, personality development, and school and organisational development at the same time.

Conclusion 5:
One of the key success factors are the teachers in schools. A major initiative for the competence development of teachers is needed. The conceptualisation and design of suitable education training measures for teachers require a systematic approach to the professional development of teachers.

Conclusion 6:
Digital competences at an organisational level need further investigation: Closing the "Society-in-the-loop" gap and learning analytics or academic analytics are examples of the new research field "digital competences at organisational level".

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Appendix 1: Further reading

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Appendix 2: Additional figures

Digital Citizenship Curriculum	K – 2			3 – 5			6 – 8			9 – 12			
	UNITS 1	2	3	UNITS 1	2	3	UNITS 1	2	3	UNITS 1	2	3	4
Internet Safety	●	●		●		●		●			●		
Privacy & Security	●	●	●	●	●	●	●		●			●	●
Relationships & Communication	●	●	●	●	●	●	●	●	●	●	●	●	●
Cyberbullying & Digital Drama		●		●		●	●		●	●		●	●
Digital Footprint & Reputation		●		●	●	●		●	●	●	●	●	●
Self-image & Identity				●	●	●	●	●	●	●	●		
Information Literacy	●	●	●	●	●	●	●	●	●	●	●	●	●
Creative Credit & Copyright	●			●	●		●	●	●	●		●	●

Figure 3.12. The digital citizenship curriculum, as proposed by Common Sense Media, Inc. (2017), a non-profit organisation, ranging from kindergarten (K) to twelfth grade.
Example for a digital citizenship curriculum (based on the eight WEF competences)

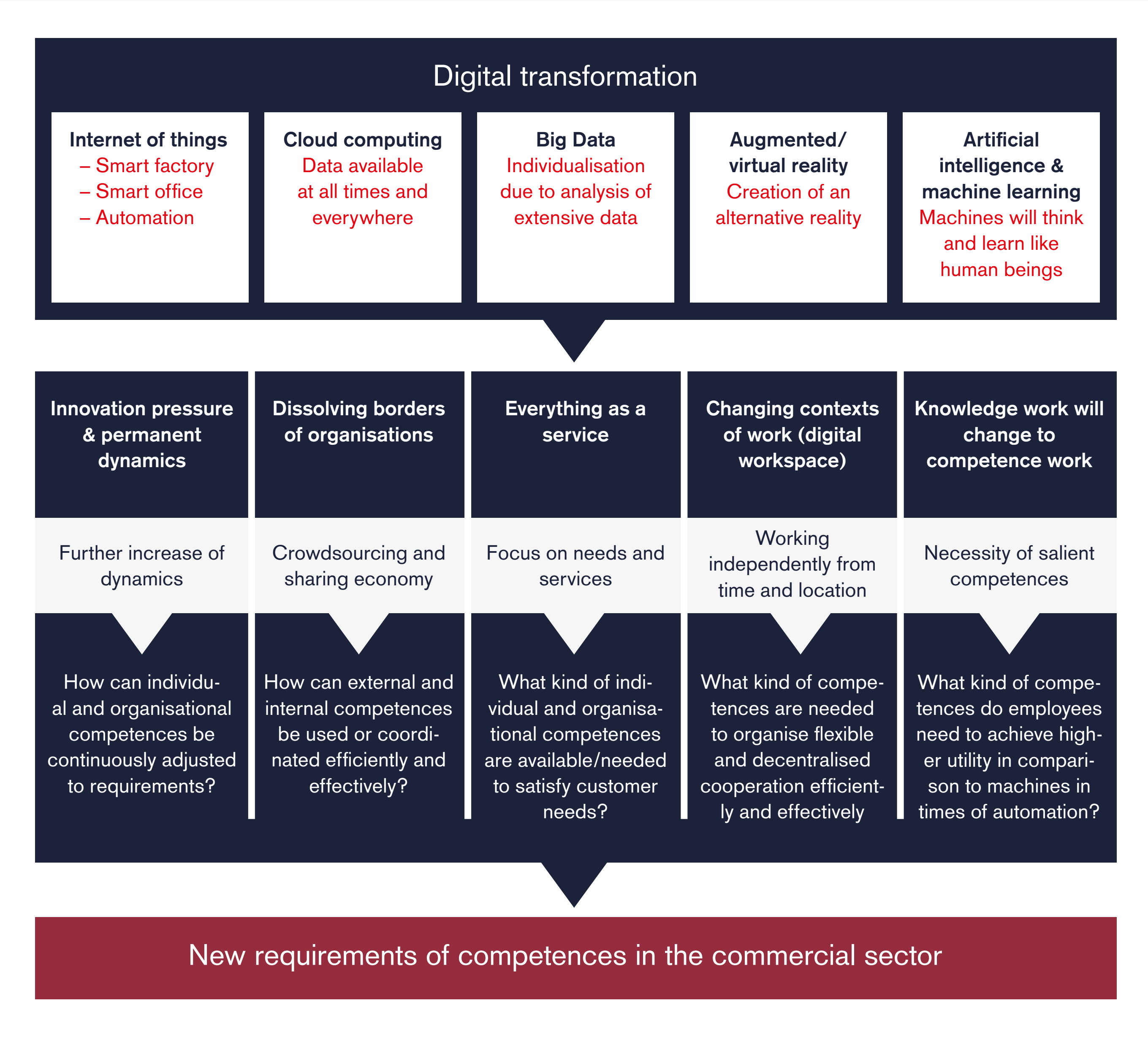

Figure 3.13. A conceptual overview of new requirements in competences for vocational school (due to the digital transformation).
New requirements of competences due to digital transformation

Glossary

Term	Description
architectural innovation	see supply-side DI
artificial intelligence (AI)	Machines with the ability or goal of exhibiting the abilities of a flexible, rational agent, who is capable of reasoning, problem solving, planning, learning, perception, etc.
attribute	Characteristic of a product or service that appeals to customers, derived from functionality, reliability, convenience, and/or price.
capital-biased technological change	Technological innovations that lead to more capital-intensive production processes and thus require less labour input.
circular flow model (CFM)	A simplified depiction of a national economy, divided into three actors (firms, government, households) and two market places (product market, resource market). The actors exchange either money, products, or resources among one another through the two marketplaces, except for the government, which directly raises taxes from both firms and households.
creative destruction	As a metaphor for the disruptive process of innovation and most famously discussed by Schumpeter (1942), creative destruction is concerned with “the process of industrial mutation that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one. This process of Creative Destruction is the essential fact about capitalism.”
demand-side DI	According to the distinction suggested by Gans (2016), this subform of DI involves “an established firm missing a certain kind of technological opportunity.” The company’s failing is based on its existing cost structure, which makes the marketing of the new technology risky and financially unattractive.
disruptive innovation (DI)	Christensen (2000) introduced DI as the reason why good companies fail, by continuously doing what made them successful: adhering to good management practices, listening carefully to customers, and investing in new technologies; these increase customer satisfaction and revenues. It is based in a change of the dominant driver customers value and can be subdivided into demand-side and supply-side forms.
dominant design	A technological feature of a product that is the de facto standard which dominates the market.
driver	see attribute
Icarus paradox	Miller (1992): The Icarus paradox is that companies often fail after becoming extremely successful. Their success becomes their pitfall, as overconfidence leads to rigidity, an undesirable form of organisational resilience.
incremental innovation	Small changes in technological development which may or may not be disruptive in nature. The change from large hard drive disks to smaller ones was minor in terms of technology but it disrupted the US computer industry.
job polarisation	Loss of middle-skilled jobs due to technological changes which favour either high-skilled or low-skilled employees. This is possible due to the high level of routine tasks in middle-skilled jobs. It is more difficult to automate low-skilled jobs, which involve a high degree of manual labour.
labour share	That part of the income side of GDP which is earned by labour, in contrast to capital (machinery, land, etc.). Industries with a labour force which has higher skills typically have a higher degree of labour share.
Luddite fallacy	Named after “Luddites”, textile workers in 19th century England, who destroyed machinery. The fallacy is concerned with the belief in long-term technological unemployment; many economists do not find support for such long-term effects.
machine learning (ML)	Algorithms that give a computer the ability to learn from data without being explicitly programmed to do so. Artificial neural networks are one example of machine learning.
occupational obsolescence	A term proposed by Tugwell (1931) as an alternative to technological unemployment; as technological change is both desirable and not stoppable.
organisational resilience	The ability of an organisation to return to a pre-crisis state or even prevent it from being affected by such a crisis.

paradox of abundance	The scarcity of a product or service (partially) defines its price. Abundance therefore is desirable from a household's point of view, as this makes the product or service cheap or even freely available. However, with regard to labour, scarcity is desirable, as this guarantees income for households. Additionally, although it might be desirable to not have to work due to the abundance of labour supply, as it increases leisure, in the absence of financial income this abundance is not desirable. Thus, with regard to labour, abundance is a paradoxical phenomenon.
Polanyi's paradox	"We know more than we can tell": Humans can perform tasks without being able to explain how (either process or functions).
radical innovation	A radical change in technology which need not be disruptive. For instance, the innovation from turboprops to jet engines did not disrupt air travel, although the technology used is radically different.
supply-side DI	According to the distinction suggested by Gans (2016), this subform of DI "arises when an established firm becomes incapable of taking advantages of a technological opportunity." The company's failing is based on its inability to absorb the new logic of production or architecture of the good sold.
sustaining innovation	No matter how radical, this type of innovation does not lead to a disruption of incumbents and thus is the opposite of a disruptive innovation.
technological unemployment	The loss of jobs caused by technological changes, closely related to the concept of creative destruction.

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Abbreviations

AI	artificial intelligence
aML	automatic machine learning
API	application programming interface
BMWi	Bundesministerium für Wirtschaft und Energie
CAS	Certificat of Advanced Studies
CBAL	Cognitively Based Assessment of, for, and as Learning
cf.	compare
CFM	Circular flow model
CSE	Computer Science Education
CSER	Computer Science Education Research
CSSI	Conseil suisse de la science et de l'innovation/ Consiglio svizzero della scienza e dell'innovazione
CTI	Commission for Technology and Innovation
DESI	Digital Economy and Society Index
DI	disruptive innovation
DIY	do-it-yourself
doi	digital object identifier
DUI	Delegation for the usage of the internet
Ed./Eds.	editor/s
EFI	Commission of Experts for Research and Innovation
e.g.	for example
EOB	employee-owned enterprise
EPF	École polytechnique fédéral
ERI	education, research, and innovation
etc.	et cetera
ETH	Eidgenössische Technische Hochschule
EU	European Union
FHNW	Fachhochschule Nordwestschweiz
FIFA	Fédération Internationale de Football Association
GDP	gross domestic product
HDD	harddisk drives
HEI	higher education institution
HITL	human-in-the-loop
HSW	Hochschule für Wirtschaft
ICILS	International Computer and Information Literacy Study
ICT	information and communications technology
IDSIA	Istituto Dalle Molle di Studi sull'Intelligenza Artificiale
i.e.	that is
IEA	International Association for the Evaluation of Educational Achievement
IGLU	Internationale Grundschul-Lese-Untersuchung
IL	information literacy
ILO	International Labour Organization
iML	interactive machine learning
IST	information society technology
IT	information technology
KMK	Kulturministerkonferenz
KOF	Konjunkturforschungsstelle
KTT	knowledge and technology transfer
MAS	Master of Advanced Studies
MIT	Massachusetts Institute of Technology
ML	machine learning
MOOC	massive open online course
MRU	master research unit
NASA	National Aeronautics and Space Administration
NCCR	National Centres of Competence in Research
No.	number
NPO	non-profit organisation
NSF	US National Science Foundation
OECD	Organisation for Economic Co-operation and Development
p./pp.	page/s
para./paras.	paragraph/s
PH	Pädagogische Hochschule
PISA	Programme for International Student Assessment
SBFI	State Secretariat for Education, Research and Innovation
SD	standard deviation
SECO	State Secretariat for Economic Affairs
SERI	State Secretariat for Education, Research and Innovation
SITL	society-in-the-loop
SME	small and medium-sized enterprises
SMS	Short Message Service
SNSF	Swiss National Science Foundation
SSIC	Swiss Science and Innovation Council
STEM	science, technology, engineering and mathematics
SUPSI	Scuola universitaria professionale della Svizzera italiana
SWIR	Schweizerischer Wissenschafts- und Innovationsrat
TIMSS	Trends in International Mathematics and Science Study
UK	United Kingdom
USA	United States of America
USI	Università della Svizzera italiana
UZH	University of Zurich
VC	venture capital
VET	vocational education and training
Vol.	volume
WBF	Federal Department of Economic Affairs, Education and Research

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