education sciences

Review

Training and Preparing Tomorrow's Workforce for the Fourth Industrial Revolution

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Abstract: We call for a paradigm shift in engineering education. We are entering the era of the Fourth Industrial Revolution ("4IR"), accelerated by Artificial Intelligence ("AI"). Disruptive changes affect all industrial sectors and society, leading to increased uncertainty that makes it impossible to predict what lies ahead. Therefore, gradual cultural change in education is no longer an option to ease social pain. The vast majority of engineering education and training systems, which have remained largely static and underinvested for decades, are inadequate for the emerging 4IR and AI labour markets. Nevertheless, some positive developments can be observed in the reorientation of the engineering education sector. Novel approaches to engineering education are already providing distinctive, technology-enhanced, personalised, student-centred curriculum experiences within an integrated and unified education system. We need to educate engineering students for a future whose key characteristics are volatility, uncertainty, complexity and ambiguity ("VUCA"). Talent and skills gaps are expected to increase in all industries in the coming years. The authors argue for an engineering curriculum that combines timeless didactic traditions such as Socratic inquiry, mastery-based and project-based learning and first-principles thinking with novel elements, e.g., student-centred active and e-learning with a focus on case studies, as well as visualization/metaverse and gamification elements discussed in this paper, and a refocusing of engineering skills and knowledge enhanced by AI on human qualities such as creativity, empathy and dexterity. These skills strengthen engineering students' perceptions of the world and the decisions they make as a result. This 4IR engineering curriculum will prepare engineering students to become curious engineers and excellent collaborators who navigate increasingly complex multistakeholder ecosystems.

Keywords: future of engineering; future of education; future of work; online learning; game-based learning; gamification; serious games; metaverse; didactics; emerging educational technologies; Fourth Industrial Revolution (4IR); Artificial Intelligence (AI); skills gap; ethics

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1. Drivers of Change in Education—Are We Prepared?

"The illiterate of the 21st century will not be those who cannot read and write, but those who cannot learn, unlearn, and relearn". Alvin Toffler (1928–2016)

Humankind in the 21st century is faced with numerous very complex and global challenges and risks, such as climate-change mitigation and adaptation, extreme weather, human environmental damage, infectious diseases, biodiversity loss, natural resource crises, failure or increasing cyber vulnerability of critical infrastructure, water crises and failure of long-term strategic infrastructure and urban planning [1], just to address some of them. Accordingly, the earth is a planet of finite resources, and its growing population currently consumes them at a rate that cannot be sustained. Widely reported warnings have emphasized the need to develop new sources of energy while preventing or reversing the degradation of the environment [2].

It is not the intention of this article to provide a ranking of these scenarios with respect of their importance. This would be already a part of the problem-solving process. The World Economic Forum's Global Risk Report 2022 identified "climate action failure", "extreme weather" and "biodiversity loss" as the three most severe risks on a global scale for the next 10 years ([1], p. 14)). While in previous years, the top global risks included economic, geopolitical, societal, and technological risks, for the first time the three major risks are climate-related.

Characteristic of these multi-level and wicked problems is their enormous complexity and thus the difficulty in designing and implementing effective mitigation measures. The systemic behaviour of such complex systems is by no means completely predictable and therefore not easily controllable by single or even a series of interventions to direct the system towards the desired outcome [3]. Complex systems can react very surprisingly and produce undesirable effects that no one had thought of before. This is the nature of complexity, even if it contradicts our desire to have total control over our systems. This does not mean that we should fall into resignation and give up our efforts. The opposite should be the case. However, we must not simply react and must include the characteristics of complex systems in our problem-solving process. We cannot pretend that we always know exactly what to do and that everything will be better if only everyone is convinced of a certain strategy. In complex systems, there is no one-size-fits-all solution. In general, the problem-solving process is more like a step-by-step implementation strategy with continuous monitoring of measurable results and agile adjustment if the desired results are not achieved [4].

Our problem-solving processes need to take much more account of this incontrovertible systems-theoretical knowledge of complex systems. In our political systems, the opposite is the case. Outlined measures, once perceived as correct, are often stubbornly defended after their implementation, although reality and the factual situation have long since called them into question again [5–8].

This means that systemic approaches to problem-solving processes are needed, involving rapidly adaptive, iterative, multidisciplinary and highly dialogical multi-stakeholder processes. Long-cycle and short-cycle processes need to be integrated to enable a systemic response. This approach is far from how engineers are trained today, although engineering solutions are and will be a major contributor to solutions [9].

The engineering profession needs to bear these challenges, take on more responsibility [10,11] and include a broader systemic approach. A business-as-usual attitude in the face of such substantial challenges will not be the responsible course of action [12].

The fourteen Grand Challenges for Engineering in the 21st century (Figure 1) developed by the U.S. National Academy of Engineering [13] can be used as a guideline for future-ready universities to design curricula and identify impactful research areas. Foremost among the challenges are those that must be met to ensure the future itself.

An example of such enormous complexity is the EU's new Taxonomy Regulation [14], which aims to support the transformation of the EU economy to achieve the goals of the European Union's Green Deal [15] and Path to The Digital Decade [16], including the 2050 climate neutrality target, matching with the fourteen Grand Challenges for Engineering in the 21st century [13] developed by the U.S. National Academy of Engineering (depicted in Figure 1). Thus, theses fourteen Grand Challenges can be used as a matchmaking-guideline for universities in alignment with the Environment, Social and Governance (ESG) Taxonomy Objectives of the European Union [17].

Engineers need to be trained to understand, critically reflect, and respond to such complexities, even when they are in the political arena. This next generation of engineers must be well equipped to (a) contribute to society, (b) lead and shape global issues, (c) identify and solve technical problems, and (d) find, articulate and pursue the societal opportunities of tomorrow [18].

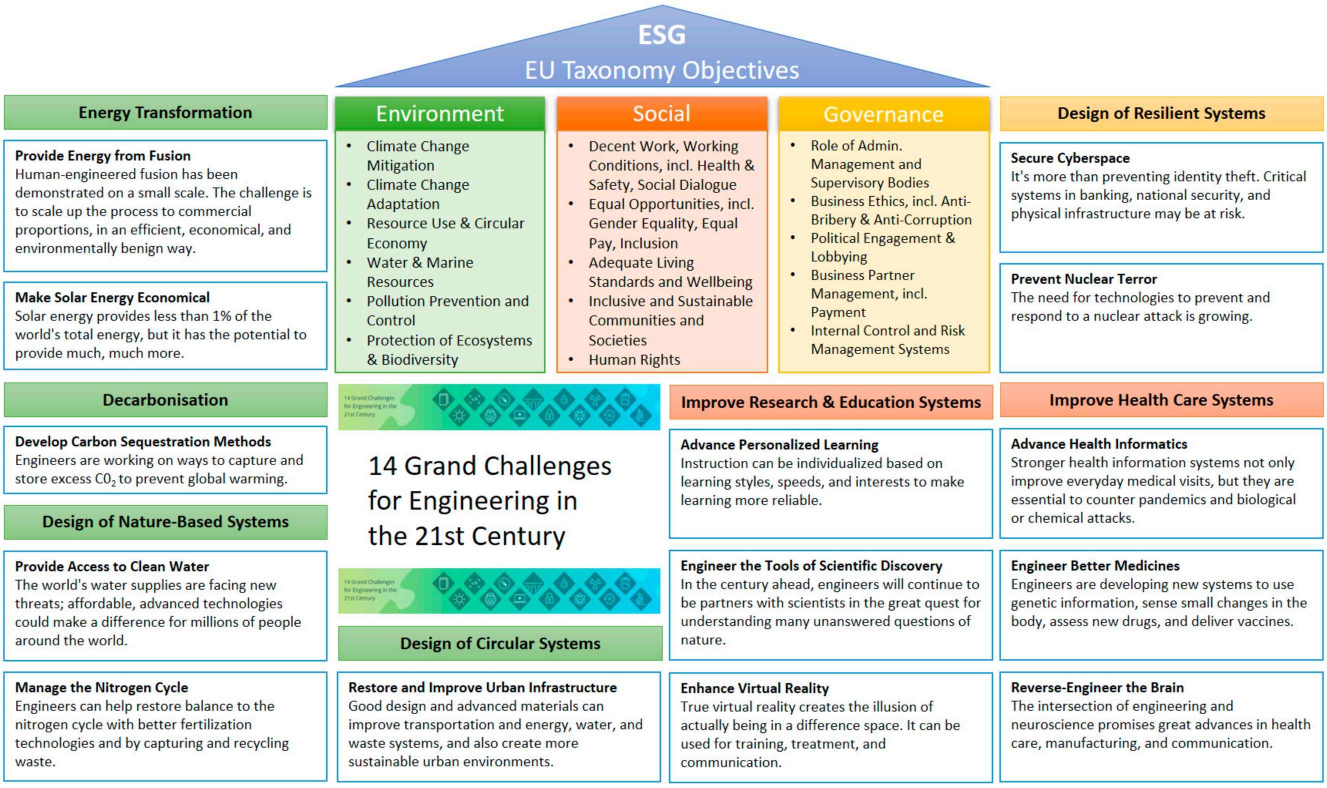


Figure 1. ESG EU Taxonomy Objectives matching the fourteen Grand Challenges for Engineering in the 21st Century, based on authors own research and depiction.

2. Tomorrow's Skills in a Fast-Changing World

The outcome of discussions during the World Economic Forum's Annual Meeting 2018 [19] supports our empirical findings. When we asked the top three most critical areas of transformation in engineering, Chief Executive Officers of the industry prioritized the key areas as follows (see survey results summarized in Figure 2): Attracting new talent and building up required skills (74%), integrating and collaborating across the value chain (65%) and adopting advanced technologies on a large scale (61%), using digital models throughout processes end-to-end (30%), redesigning core operational processes with customer orientation (22%), enabling adaptiveness, agility and change management (17%); embracing new digital business opportunities (13%); ensuring access to data and cybersecurity (9%); systematically reviewing and adapting product and segment portfolio (9%). Similarly, during the Annual Summit of McKinsey's Global Infrastructure Initiative [20] in the fall of 2018, industry executives were asked what the most significant challenges will be for industry leaders in the next decade:

- Developing a culture of innovation that embraces disruptive technologies;
- attracting and retaining the right talent, moving to more collaborative, less adversarial contractual arrangements;
- developing a more diverse and inclusive workforce were the topmost challenges identified.

These responses accurately express the skills required of engineers to find answers to complex and systemic problems. Engineers should take a broader approach and contextualize their technology-centric solutions much more. Dialog and collaborative work with other disciplines play a crucial role here.

In the following, exactly these three aspects are taken up and their impact on the education of engineers is discussed.

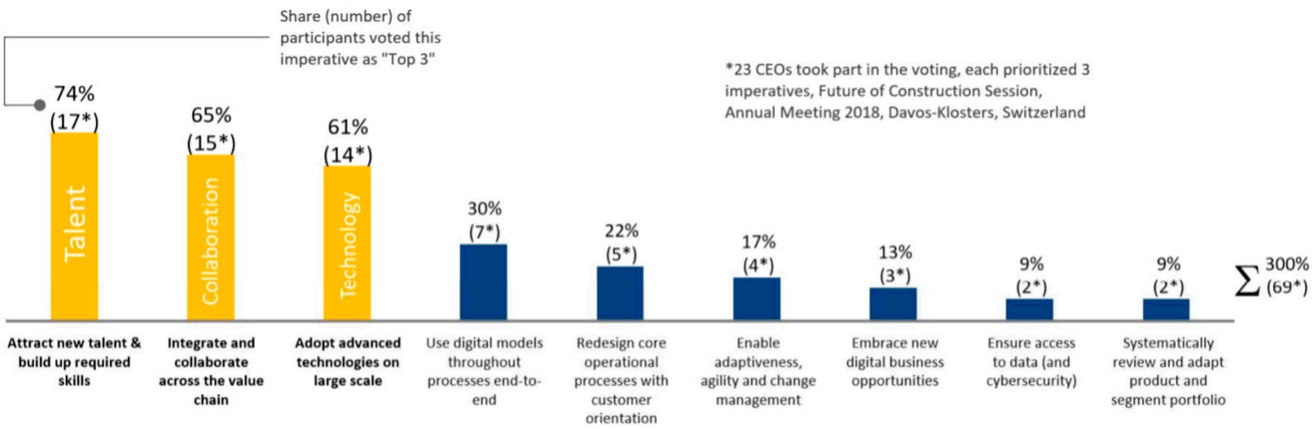


Figure 2. CEO survey on the top three most critical areas of transformation in engineering, based on authors own research (* 23 CEO had three votes each to prioritize their top three imperatives).

2.1. Developing a Culture of Innovation That Embraces Disruptive Technologies: Preparing for the 4th Industrial Revolution—Matching Education Demand with Education Supply

Systemic solutions have to consider a multi-perspective approach embedding the solution into the context. With this respect, we cannot ignore that we have already arrived amid the next industrial revolution that fundamentally transforms our economies, societies, and even who we are as human beings [21]. Thinking and acting around this Fourth Industrial Revolution (4IR) [22,23]—which is characterized by a range of new technologies [24] that are fusing the physical, digital and biological worlds—demand that we acquire new skills and a new style of leadership [25]. 4IR will lead to an increasing individualisation and virtualisation of education, it will strengthen the project-based and multidisciplinary character of engineering education and accelerate the development of interactive educational resources [26]. Technical revolutions certainly have a strong impact on how the workforce is trained and educated.

In industrial history (see Table 1), the first industrial revolution driven by the steam engine led to the emergence of labour specialisations, the establishment of trade schools and the development of (technical) universities. During the 2nd industrial revolution driven by electricity, multi-level training systems for industry were then developed, training became increasingly standardised, while the prestige of engineering education rose rapidly. In the second half of the 20th century, the 3rd industrial revolution driven by information technology led to the integration and globalisation of education, academic mobility increased and with it international educational standards developed [26].

In view of the profound changes brought about by the 4th industrial revolution, the training requirements for the engineering profession will change significantly [27]. To successfully meet the environmental, societal and financial challenges of an increasingly complex and hyper-connected world, we must collectively and fundamentally rethink or even reinvent our engineering profession and with it the underlying education system [28,29]. Therefore, we need to ask ourselves how we can create a more holistic engineering curriculum that takes into account industrial changes and adequately prepares our young and established engineers for the future. The 4IR calls for the engineering profession to constantly renew itself, better market its services and breed a future generation of engineers. This next generation of engineers must be well equipped to (a) contribute to society, (b) lead and shape global issues, (c) identify and solve technical problems, and (d) find, articulate and pursue the societal opportunities of tomorrow [30].

According to [27], the exponential pace of technological change requires an urgent transformation of education. Educational systems must undergo transformative change to ensure inclusive and sustainable development for all, not just the privileged few. As António Guterres has stressed during his opening speech at the United Nations' Transforming Education Summit 2022 [31]:

> *"The education systems [. . .] must help people learn how to learn, with a focus on problem-solving and collaboration [. . .] provide the foundations for learning, from reading, writing and mathematics to scientific, digital, social and emotional skills [. . .] develop students' capacity to adapt to the rapidly changing world of work [. . . and] be accessible to all from the earliest stages and throughout their lives".*

We face fundamental ethical issues in using the knowledge and skills we possess to create new products and opportunities. Introducing novel and more effective models of education to meet talent needs will shorten the period of "social pain" and maximise the period of "prosperity" for all (also see the evolution of education versus the evolution of technology over time in Figure 3). The authors of this paper believe that the race between technology and education [26] might be decided in favour of technology since education might fail to catch up with the accelerated rate of technological change in the years to come. However, the exponential technologies of the Fourth Industrial Revolution (4IR) will also support humanity to meet the United Nations' Sustainable Development Goals [31].

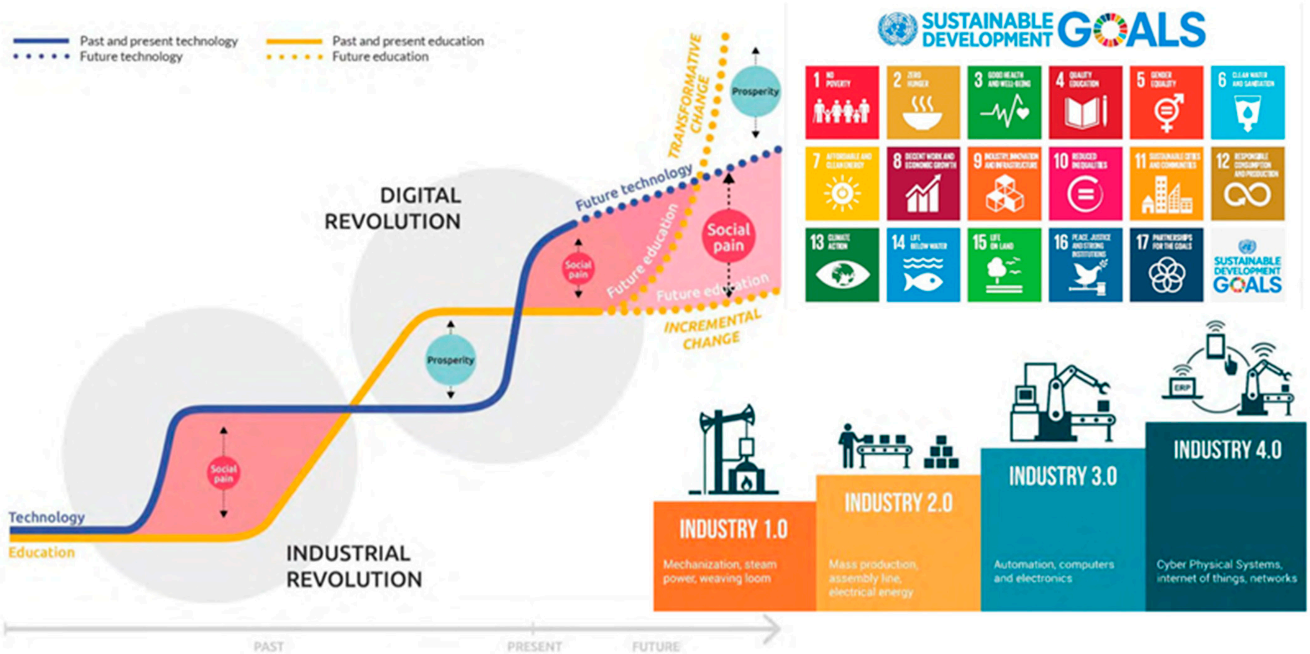


Figure 3. The race between technology and education as an opportunity to meet the United Nations' Sustainable Development Goals (Reprinted with permission from OECD (2019) [32], pp. 6–7).

2.2. Attracting and Retaining the Right Talent: Closing the Talent and Skills Gap

Skills shortages in all sectors will increase in the Fourth Industrial Revolution [33].

Access to skilled labour is already a key factor that separates successful companies from unsuccessful ones. In an increasingly data-driven future, the looming skills gap in Europe will result in 1.67 million unfilled ICT professional jobs by 2025, more than double today's (2022) figures [34]. This gap is expected to widen in the coming decades.

Rapid advances in AI, robotics and other emerging technologies are occurring in ever-shorter cycles and changing the nature of the tasks to be done—and the skills required to do them—faster than ever before. According to the World Economic Forum, about 100 million new jobs could be created worldwide by 2025 as a result of the new division of labour between humans, machines and algorithms [35]. Thus, automation could result in a net addition of 12 million jobs as robots are predicted eliminate 85 million jobs. There will also be strong demand for technical skills such as programming and application development, along with skills that computers do not easily master, such as creative thinking, problem solving and negotiation [36,37]. The 4IR is transforming the world of work. Technology is advancing faster than humans, changing both jobs and the skills needed to compete [38].

Research by McKinsey [39] suggests that globally, about half of the jobs people do today will be eliminated by automation, and a survey of business leaders by the World Economic Forum [40] suggests that 42% of the core skills required today will change significantly. The OECD estimates that 14% of existing jobs could be eliminated by automation in the next 10–15 years, and another 32% are likely to change radically as individual tasks are automated [41]. As the Fourth Industrial Revolution progresses, employers are demanding a greater mix of skills [42].

Table 1. Impact of technological change on education paradigm (Reprinted with permission from the author [26]).

Period	Era	Industrial Changes	Educational Changes
18th to 19th century	1st industrial revolution	Invention of steam engine, the transition from manual labor to machine	Emergence of labor specializations, establishment of trade schools, development of technical universities
19th–beginning of 20th century	2nd industrial revolution	Transition to electricity, development of transport, communications, development of high-tech industries	Development of a multi-level training system for industry, standardization of training, enhancement of the reputation of engineering education.
2nd half of 20th to beginning of 21st century	3rd industrial revolution	Transition to telecommunication technologies, automation of production, rapid development of services	Integration and globalization of education, development of academic mobility, transition to international education standards, increase in training of specialists for services
Beginning of 21st century	4th industrial revolution	The Internet of things, integration of “cyber physical systems”, or CPS, in production processes, intelligent automation	Individualization and virtualization of education, strengthening the project-based and multidisciplinary character of engineering education, development of interactive educational resources

The 2021–2024 work programmes of Horizon Europe, which is the European Union’s flagship programme for research and innovation with a budget of €95 billion, indicate the technologies and technical skills that are needed to match the requirements of the 4IR. The “Digital, Industry, and Space” cluster focusses on research and innovation areas, including “climate neutral, circular and digitised production”, “world-leading data and computing technologies”, “AI-driven autonomous robots”, “large-scale quantum computing platform technologies”, “AI, data and robotics enabling the green transition”, “Industry 5.0”, “metaverse and digital twins for cities, industries, and critical infrastructure” and “enhanced assessment, intervention and repair of civil engineering infrastructure” [43]. Those research areas will further lead to industrial automation and, in turn, reinforce the transformation of the education system and need for new engineering curricula.

According to recent studies [44] by the World Economic Forum, the industry urgently needs new talent and skills [45] to support the adoption of new technologies that will drive the sector’s transformation to address global challenges such as climate change, resource scarcity, rapid urbanisation, the housing crisis and the infrastructure gap. However, he challenges are constantly emerging and require every engineer to learn in new ways and think far beyond traditional boundaries [46].

Over the past 50 years, the construction industry for instance has not innovated as fast as other sectors, resulting in stagnant productivity and negative impacts on the economy, society and the environment [47]. A major underlying problem is the fragmented nature of the industry, where economies of scale are difficult to achieve. As a result, human resources do not grow in line with production output, leading to pressure on wages as a means of raising prices. This leads to a persistent industry-wide shortage of skilled labour. This shortage has undermined project management and delivery, negatively impacting costs, deadlines and quality. It has also hindered the adoption of new digital twin technologies such as Building Information Modelling ("BIM") [48], automated equipment and cloud-based collaboration tools that could improve productivity [47].

To close the current talent and skills gap, companies need to strategically plan for the supply and demand of talent, improve internal learning and development programmes, and introduce new technologies that increase productivity and job satisfaction. Companies also need to update their work culture to appeal to younger workers and increase diversity, including increasing the number of women in the industry (see pillar 1, Figure 4). Industry associations should run image campaigns to promote jobs, target new talent pools, e.g., employees with appropriate skills from other industries such as gaming, create shared knowledge resources, make career paths more transparent and collaborate with universities and vocational schools on training (see pillar 2, Figure 4). [49] highlights that "lack of career development", "inadequate compensation", "uncaring/uninspiring leader", "lack of meaningful work", the most common reasons given for quitting previous jobs and has made hiring talents harder. Whereas the former two are rather traditional reasons for quitting previous jobs, the latter two confirm such change in job culture preferences of younger workers. As a consequence, the governments must use its role as regulator and principal owner of public projects to develop regulations and promote initiatives that drive innovation to make the industry more attractive. It must also harmonise standards to make projects less complex and less costly, update publicly funded apprenticeships and academic programmes to include training in new skills, and increase support for employment services [36] (see pillar 3, Figure 4).

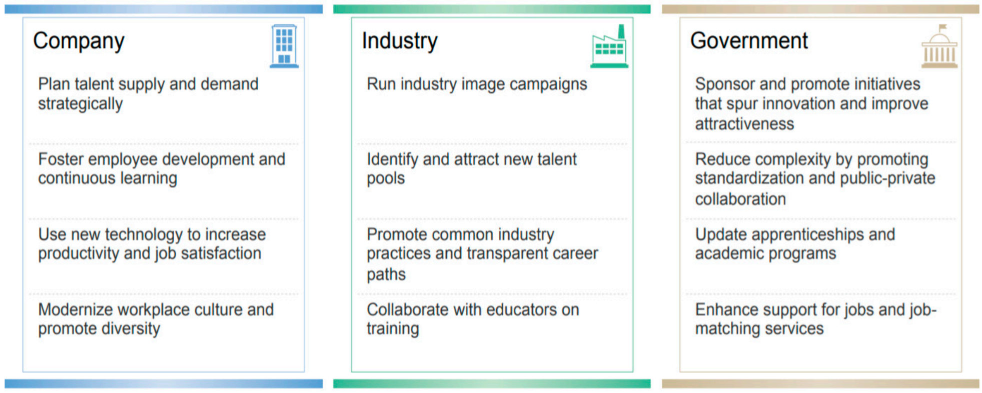


Figure 4. Three pillars to solve the industry's talent and skills gap (Reprinted with permission from the World Economic Forum [45]).

The 4IR is transforming the world of work. Technology is advancing faster than humans, changing both jobs and the skills needed to compete [38]. Research by McKinsey [39] suggests that globally, about half of the jobs people do today will be eliminated by automation, and a survey of business leaders by the World Economic Forum [40] suggests that 42% of the core skills required today will change significantly. The OECD estimates that 14% of existing jobs could be eliminated by automation in the next 10–15 years, and another 32% are likely to change radically as individual tasks are automated [41]. As the Fourth Industrial Revolution progresses, employers are demanding a greater mix of skills [42].

2.3. Differentiating Human Skills and Capabilities from AI: An Effective Solutions Framework to Future-Proof Our Education System

It is often stated that AI and automation is competing against humans. However, this is only true in a small but likely impactful field of human intelligence [50]. Due to technical developments repetitive human skills have been continuously replaced by machines. This process is now certainly pushed forward by AI and automation and challenges repetitive knowledge work. However, this push does not replace us as human beings, rather it uncages the potential to develop stronger internal human competences [51]. Three capabilities where AI is falling short in the short and medium-term have been identified recently [52]. Humans' most significant differentiators from AI are creativity, dexterity, and empathy:

- Creativity: AI can neither plan creatively nor conceptually nor strategically. AI is excellent at optimising for a specific goal, but it cannot choose its own goals or think creatively. AI also cannot think across domains or apply common sense.
- Empathy: AI cannot feel or interact with emotions such as empathy and compassion. Therefore, AI cannot make another person feel understood and cared for. Even if AI improves in this area, it will be a challenge to develop the technology to the point where people feel comfortable interacting with robots in situations that require caring and empathy, or what we might call *'human touch services'*.
- Dexterity: AI and robotics cannot perform complex physical tasks that require dexterity or precise hand-eye coordination. AI cannot deal with unfamiliar and unstructured spaces, especially those it has not observed.

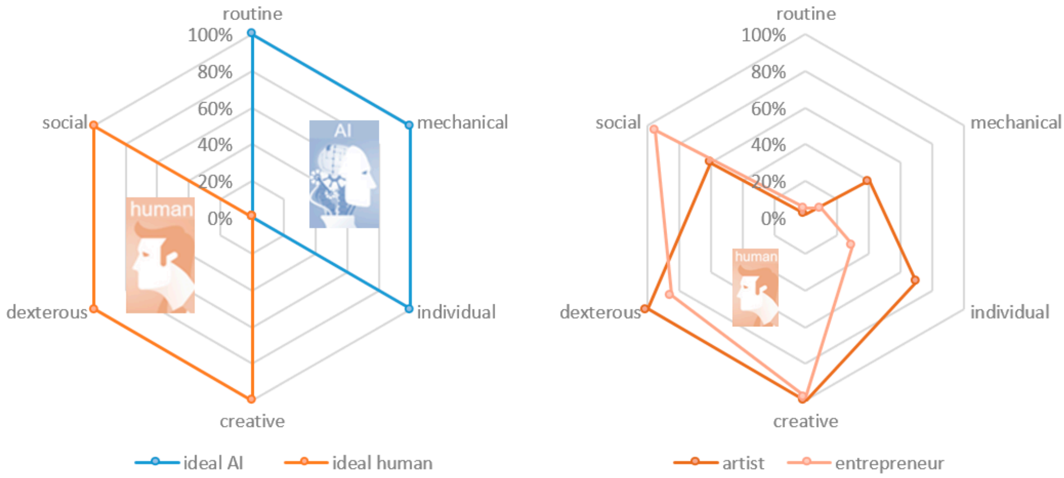
The list of such internal human competencies can be greatly expanded, e.g., self-awareness, intention, purpose and spirituality at the individual level and culture, morality and community values at the collective level, to name just a few examples. Such development will assist humans to grow in the areas of competence that distinguish humans from machines.

Figure 5a–c are exemplified outcomes from [52] and depict typical physical jobs on a dimension between mechanical and dexterous, i.e., skillful manual work. Mechanical jobs will be automated in the future and will be replaced by AI-supported machines. Cognitive jobs can be seen on a scale between routine processing and creative generation. AI algorithms will replace routine jobs, e.g., chat bots. The three axes pointing to left and bottom in Figure 5c favours humans, and the three axes pointing to the right and top favour AI.

As a consequence, in education, a business-as-usual attitude will ultimately lead to irrelevancy. Therefore, a refocussing of the universities will be required to move their teaching staff into the social-dexterous-creative quadrant, as explained in Figure 5c.

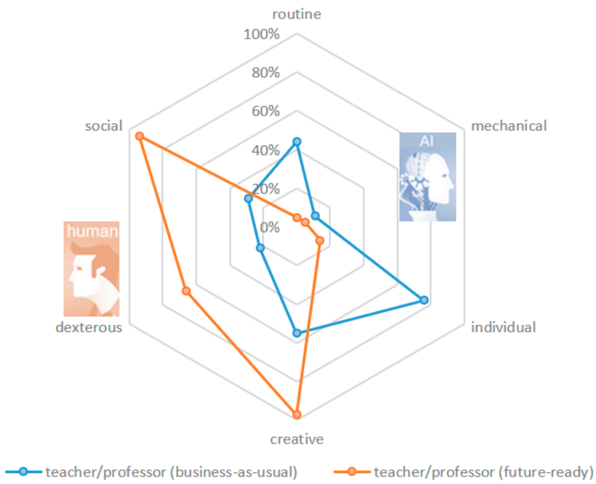
A recent survey of 1408 technology and education professionals [53] suggested that the most valuable skills in the future will be those that machines cannot yet easily replicate, like creativity, critical thinking, emotional intelligence, adaptability and collaboration. In short, people need to learn how to learn—or according to Alvin Toffler quote on the front page of this paper "*learn, unlearn, and relearn*"—because the only hedge against a fast-changing world is the ability to critically think, understand and apply first principle thinking, adapt to changed data and effectively collaborate.

According to analysis [54] from the world's largest professional-networking site LinkedIn, typical employers are looking for a combination of both hard and even more importantly soft skills, with creativity topping the list of desired attributes. According to LinkedIn Executive Chairman Jeff Weiner, the biggest skills gap he sees is soft skills. After creativity, the top soft skills were persuasion, collaboration, adaptability and time management. What most employers want, Weiner says, are written communication, oral communication, teambuilding, and leadership skills.



(**a**)

(**b**)



(**c**)

Figure 5. (**a**–**c**) Physical jobs are differentiated between mechanical and dexterous. Mechanical jobs will be automated in future and will be replaced by AI-supported machines. Cognitive jobs are differentiated between routine processing and creative generation. Routine jobs will be replaced by AI algorithms, e.g., bots. The upper right back diagonal favours humans, and the lower left front diagonal favours

AI Dimensions adopted from [52]. (**a**) on the left shows an ideal AI with maximum score for routine, mechanical, individual traits and an ideal human with maximum score for social, dexterous, creative traits. (**a**) on the right shows examples of typical traits for an entrepreneur and an artist, respectively. (**b**) on the left shows occupations that are not readily replaceable by AI, while (**b**) on the right shows occupations that are replaceable. (**c**) compares examples of a future-ready teacher with those of a business-as-usual teacher.

According to the recent World Economic Forum's The Future of Jobs report [35], the Top 10 Skills for the Future are all soft skills—with people and cognitive skills gaining precedence over others. A reported [55] 57% of leaders, including Sheryl Sandberg, former Chief Operating Officer of Meta (previously Facebook), and Eric Schmidt, former Chief Executive of Google and Executive Chairman of Alphabet, agree that soft skills are more important than hard skills in job candidates. As technologies like automation and algorithms create new high-quality jobs and wipe out others, demand for such competencies is only likely to increase. The findings chime with the World Economic Forum's Future of Jobs report [56], which concluded that "human" skills like originality, initiative and critical thinking are likely to increase in value as technology and automation advances. The Forum looked at how the desirability of those attributes is likely to evolve over time, with active learning, creativity and social influence climbing up the list. "Strengthening a soft skill is one of the best investments you can make in your career, as they never go out of style," according to LinkedIn Learning Editor, Paul Petrone. "Plus, the rise of AI is only making soft skills increasingly important, as they are precisely the type of skills robots cannot automate." The hard skills in demand also reflect the increasingly digital world, with cloud computing and AI coming out on top, with engineers in demand as more and more services and data migrate to the cloud, followed by analytical reasoning, since companies need to make decisions based on the myriad of data that is now accessible to them. People management came fourth, followed by user experience design—the process of making all these new technologies accessible and easy for humans to interact with.

The World Economic Forum [57] has developed a model for quality education during the Fourth Industrial Revolution to catalyse systemic change. It identified eight critical characteristics for learning content and learning experiences that define high-quality learning, or Education 4.0 (Figure 6).

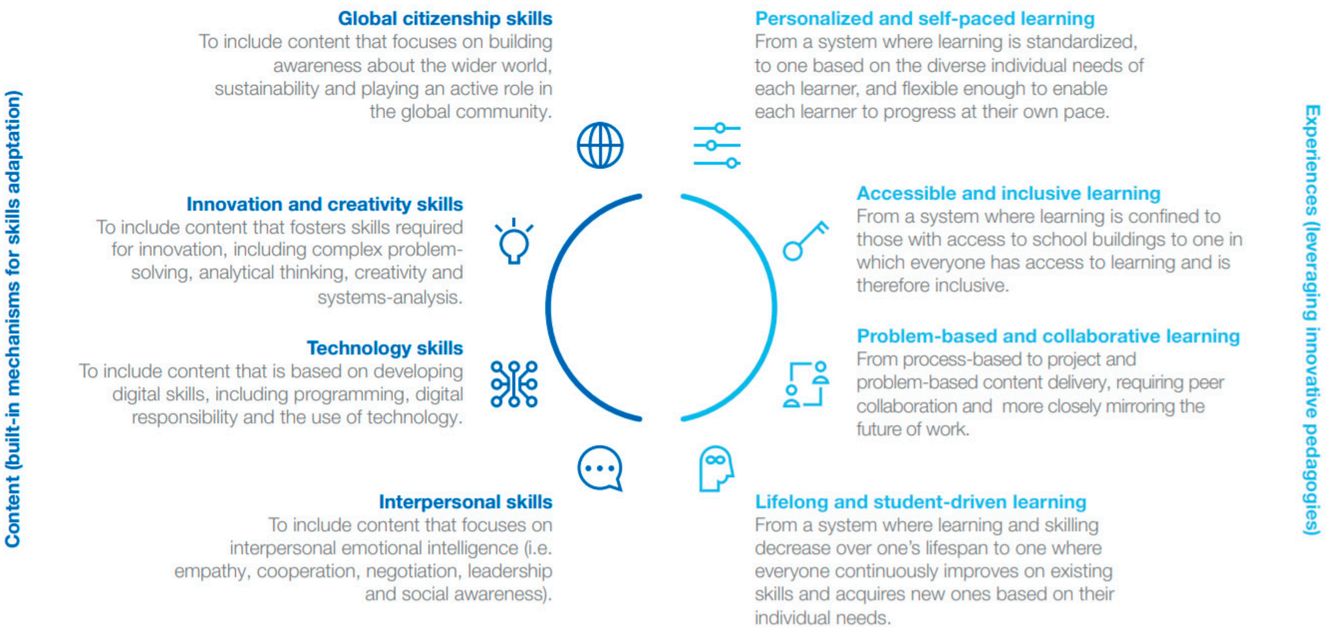


Figure 6. Education 4.0—A Global Framework for Shifting Learning Content and Experiences Towards the Needs of the Future (Reprinted with permission from World Economic Forum [57]).

3. The Necessary Transformation of the Workforce

To train hybrid intelligence systems (Figure 7), socio-technological ensembles of humans and machines [58], universities will need to redesign curricula, whereas the government has to incentivize skills required instead of providing universal basic income (UBI). To transform the human workforce to deal with the AI economic revolution [23], we will have to relearn new skills related to strategy, creativity, empathy-based social skills, and dexterity. In addition, educators will need to prepare the workforce by recalibrating new jobs towards human-AI collaboration. There are significant opportunities to reinvent many jobs and create new ones through a more profound interdependence between AI optimizations and "human touch." According to [52], a renaissance led by AI will enable and celebrate creativity, compassion, and humanity; In this new era, people will follow their passions, creativity, and talents once they have more freedom and time. AI tools will reinvent education, giving teachers AI tools to help students find their passions and talents. Education will encourage curiosity, critical thinking, and creativity. It will promote learning by doing and group activities that enhance students' emotional intelligence.

The authors think that such a competence transformation will not only lead to the development of "inner" competences of humans, it will also lead to a new level of "outer" competences, which already had been addressed elsewhere [59].

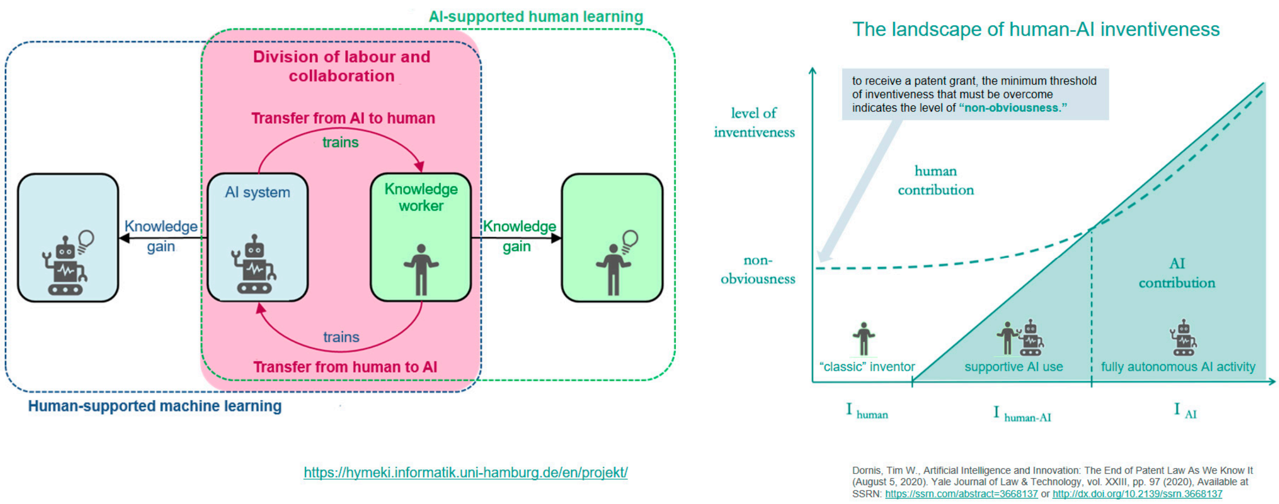


Figure 7. Human-AI-learning interaction (Reprinted with permission from the authors [60,61]).

4. A Breakthrough in Education

According to Sir Ken Robinson [62],

> *"we have to transform what is essentially an industrial model of education, a manufacturing model, which is based on linearity and conformity and batching people. [For the university of the future], we have to move to a model based more on principles of agriculture. We have to recognize that human flourishing is not a mechanical process–it's an organic process. And you cannot predict the outcome of human development. All you can do, like a farmer, is create the conditions under which they will begin to flourish".*

As a consequence, the current one-size-fits-all education system has to acknowledge that each student is different. Therefore, AI-infused schools will perhaps hold the most significant opportunity for AI in education, which is individualized learning. A personalized AI tutor could be assigned to each student. Unlike human teachers, who must consider the whole class, a virtual teacher can pay special attention to each student. In the future, teachers will play two crucial roles:

First, they will be human mentors and connectors for the students. Human teachers will be the driving force behind stimulating the students' critical thinking, creativity, empathy, and teamwork. Furthermore, the teacher will be a clarifier when a student is confused, a confronter when the student is complacent, and a comforter when the student is frustrated. In other words, teachers can focus less on the rote aspects of imparting knowledge and more on building emotional intelligence, creativity, character, values, and resilience in students. The second role that teachers will play is to direct and program the AI teacher and companion in ways that will best address the students' needs. They will do this based on their experience, wisdom, and in-depth understanding of the students' potential and dreams.

5. Case Study on Gamification, Simulations and Serious Games

An explorative case study on the topic of "Gamification, Simulations and Serious Games" was developed as part of a special internal call for proposals of the DigitALL project at the University of Applied Sciences Konstanz. DigitALL is part of the funding programme "*Strengthening Higher Education Teaching through Digitisation*" of the Foundation for Innovation in Higher Education (Stiftung Innovation in der Hochschullehre, Treuhandstiftung in Trägerschaft der Toepfer Stiftung gGmbH) and is funded with an application sum of around 3.7 million euros for a period of 3 years.

With the help of the funding, the application and success potential of "Gamification, Simulations and Serious Games" at universities could be investigated and evaluated. For this purpose, the following project goals were achieved:

1. Comprehensive understanding of the current state of the art in the field of "Gamification, Simulations and Serious Games" in teaching at universities worldwide;
2. formation of an informal network of interested parties;
3. forming an international network of subject matter experts;
4. identifying the potential for success for the application
5. compilation of the findings and stock take of accessible materials for general use on a website (output and utilisation).

Extensive design recommendations for the development and implementation of serious games for meaningful social interaction based on player preferences, needs and desires were already available from the relevant literature [63–65]. However, critical hurdles and risks were identified through additional expert interviews and, with the help of a final focus group on campus on 14 January 2022, teachers and learners were familiarised with the most promising concepts and, in this context, a tailor-made solution concept outlined in this section was discussed and developed.

5.1. Context and Initial Situation

Education 4.0 is a new educational paradigm designed to address the needs and opportunities of the Fourth Industrial Revolution. Essentially, Education 4.0 is based on the concept of learning by doing, where students are encouraged to learn and discover different things in unique ways by experimenting [66]. In addition to applying the technologies of Industry 4.0, Education 4.0 relies on concepts such as gamification, simulations and serious games [67].

Computer games that, in addition to their entertainment value, specifically promote the transfer of knowledge and skills or support behavioural changes are referred to as serious games. Serious games in education, especially at universities, have not yet been fully researched, although the pedagogical application of gamification, serious games and computer simulations has been known as an educational method for a long time and has demonstrably significant development potential [68,69].

Recent studies, even before COVID-19, point to increasing numbers of users and ever greater integration of information and communication technology into existing educational processes [70,71] to enhance the attractiveness of teaching and learning [72–74]. In this context, modern, well-designed learning games improve the user's problem-solving skills, enable effective learning, and can build bridges between theory and practical application by learning, retrieving and assessing skills and knowledge in a positive, motivating, safe, simulated environment [75,76]. In addition, game data can be analysed relatively easily to provide useful information for performance measurement, assessment and improvement, but also for enhancing the learning environment [77].

Although interest in games in education has increased over the last decade, there is still much need for research on serious games and their effectiveness. Moreover, theoretical and practical exploration requires interdisciplinary collaboration [78].

5.2. Definitions of Gamification, Game Elements and Dynamics

Gamification is derived from the English word "game" and refers to the use of playful elements in learning and working contexts [79,80]. Dorling and McCaffery [81] define gamification as the "application of game elements and theories in 'non-game contexts' with the intention of changing behaviour, or motivating and engaging users".

Game elements are "rules, features, dynamics, principles and control mechanisms of games" [81]. Game elements, when combined, can "influence behaviour by potentially tapping into the full range of human emotions and enhancing user motivation" [81].

The ongoing combination of game elements makes the game engaging and interesting. It is called game dynamics [82].

5.3. Gamification as a Teaching Tool

Gamification and the use of serious games in schools and universities aim to convey teaching content, to establish a certain behaviour or to change it. Accordingly, the goal lies outside the game. It is used as a means of teaching (Figure 8).

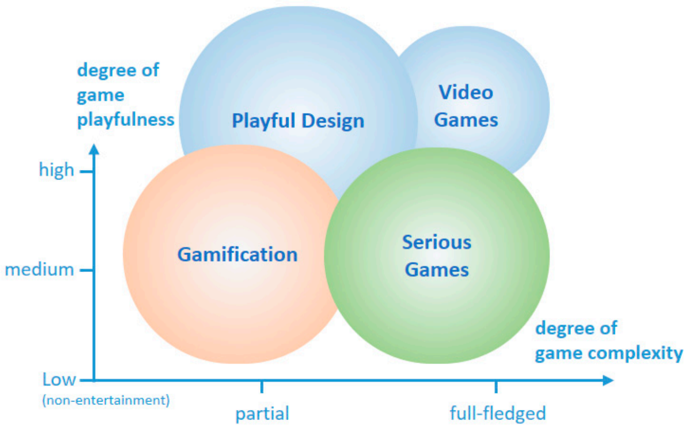


Figure 8. Serious games and gamification for teaching and entertainment purposes (e.g., [82], p. 21), based on authors own research.

Gamification is the use of individual elements and ideas from (computer) games. In contrast, when using serious games, the entire structure, the game design, is adopted unchanged. A component of serious games is usually a realistic, interactive digital simulation of the scenario in which the players move.

It is well known that the use of game elements can contribute to teaching success. However, the mechanisms involved are highly complex: "The better it is understood what makes games so attractive to people, why playing games captivates and motivates people in such a way, the more likely it will be possible to apply similar principles to get people to engage in useful activities they are reluctant to do" ([83], p. 107).

5.4. Nudging in Education

In education, desired behaviour is often difficult to achieve [84]. Nudging is therefore to be understood literally: It is a "*gentle hint*" intended to direct attention in a certain direction and open up options for learning. However, nudging is not a coercive tool. It must always be possible to decide against nudging without much effort. Thus, nudging is one of the most effective strategies from behavioural economics that aims to influence behaviour by changing the environment.

Nudging theory [85] is a framework commonly used in the behavioural sciences and behavioural economics, which states that subtle and indirect changes in the environment are an effective way to change people's behaviour and decision-making. Recent studies [86] suggest that it could also be a valuable tool for influencing behaviour in education. However, nudging is still rarely used in education.

When applying nudging in education, it is important to remember that a focus on the long-term effects and underlying processes of a nudge is necessary for successful implementation. In order to facilitate the implementation of nudging in education, it is necessary to distinguish between different nudges that are relevant for overcoming typical problems. Hansen and Jespersen [87] distinguish between type 1 and type 2 nudges and between transparent and non-transparent nudges, resulting in four nudge categories (see Figures 9 and 10, respectively). Each of these nudge categories is suitable for different educational goals. This results in a decision matrix that can help researchers and practitioners develop nudges for an educational context (see Figure 11).

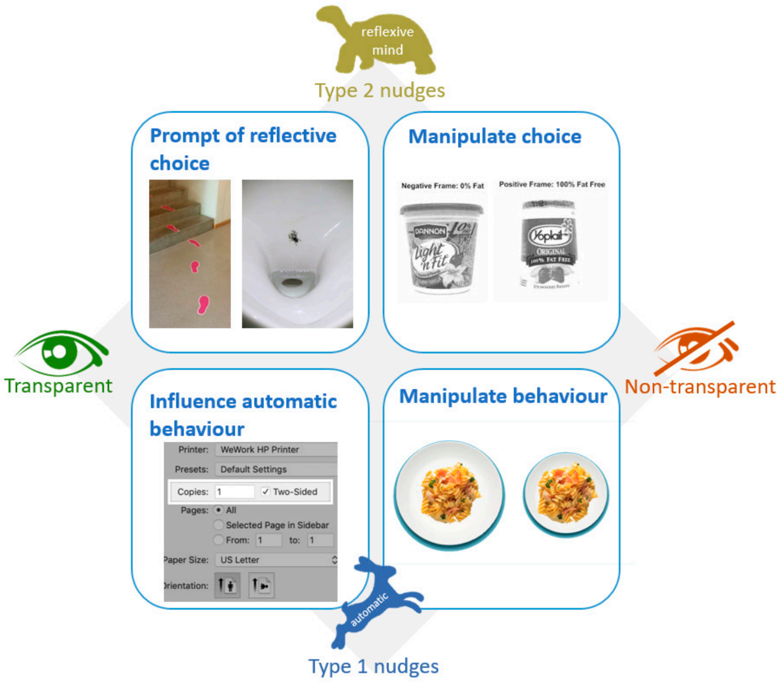


Figure 9. Matrix depicting the four categories of nudges with corresponding examples, based on authors own research.

5.5. What Is the Case for Gamification in Education?

Gamification is more appealing to learners through playful elements, which increases motivation to learn. A quick feedback system promotes a sense of achievement and thus increases motivation. Failure is seen as part of the process and thus encourages trying out new solutions. A better focus is created through a concrete, tangible goal. Cooperative play strengthens the ability to work in a team. According to [88] names four dimensions of freedoms of play:

"The freedom to fail: Failure in play creates the individual or collective conditions that lead to improvement or (learning) progress. However, failure in learning processes has a negative image. The failure of a solution is perceived as a personal defeat and not as an opportunity for improvement. This effect is reinforced by the linking of performance certificates (grades) and work results.

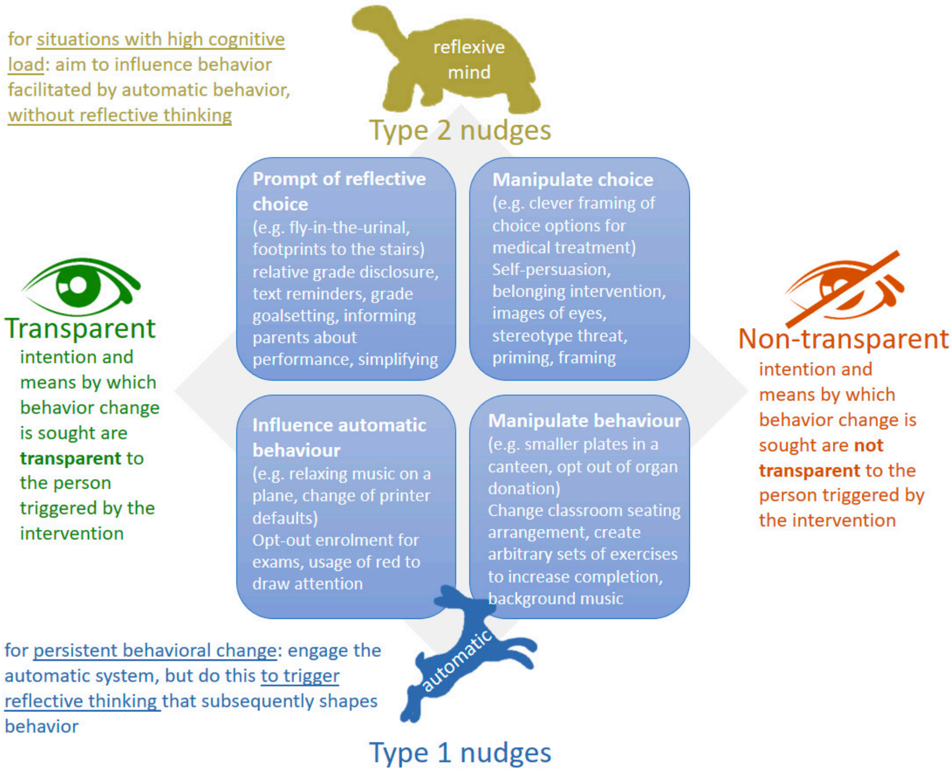


Figure 10. Matrix depicting the four categories of nudges: The transparent Type 2 nudge achieves behavioural change by engaging the reflective system, while the goal of this nudge is clear (top left). A non-transparent Type 2 nudge use the reflective system, but does so in a way that its goal is not necessarily evident (top right). A transparent Type 1 nudge causes behavioural change without engaging the reflective system but informs the targeted individuals of its purpose or at least works in such a manner that its purpose is clear (bottom left). A non-transparent Type 1 nudge is intended to support behavioural change without engaging the reflective system and of which the intent is unlikely to be recognized (bottom right).

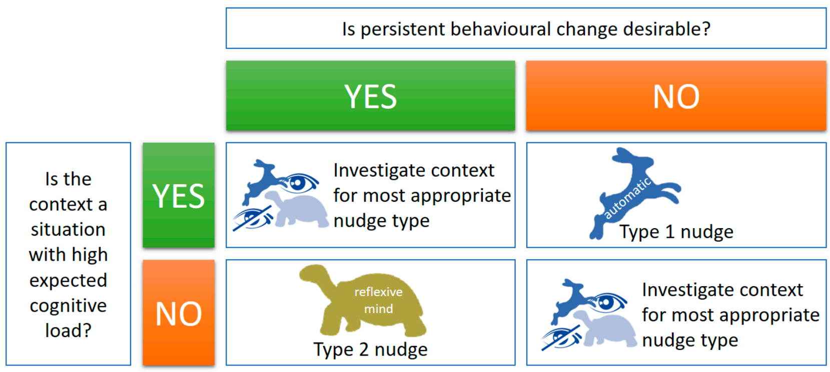


Figure 11. Decision matrix that can be used to decide which type of nudge to implement in a given situation, whether the previously designed nudge fits the environment, or to explain the success or failure of a previously implemented nudge in education. The decision to use a transparent or non-transparent nudge is largely context-dependent, but Weijers et al. [86] encourages transparent nudges over non-transparent nudges (Reprinted with permission from the authors [86]).

The freedom to experiment: Games allow individuals to try out alternative solutions to achieve the game goals, in the hope of finding the ideal (right) way on their own. Solving professional challenges is similar. Instead of a defined solution, there are various strategies from which the person concerned selects the appropriate one according to criteria he or she has chosen (e.g., efficiency).

The freedom to assume different identities: Games encourage individuals to look at problems from different perspectives by taking on different roles or mastering challenges in a team. This must also be taken into account within university teaching. Within the framework of business games, for example, in which students slip into different professional roles, complex issues from everyday business life can be taught in a practical way.

The freedom of effort: In game situations, individuals take control. They can take breaks, develop new solution strategies through reflection and try them out at the time of their choice. The level of activity can thus be adapted to individual (learning) prerequisites such as attention span or ability to concentrate." ([88] in the German translation by [89], p. 216f).

5.6. How can Educators Implement Gamification?

Preliminary remark it has to be noted that research on gamification is still in its infancy. Therefore, to date, there is no ready-made "step-by-step guide" for a correct application. Considering that context, we would like to motivate teachers to try out the concept of gamification and get feedback from learners. As an excellent starting point, Huang and Soman [90] provide a good introduction for teachers in in form of a *Practitioners Guide To Gamification of Education*. Here, state-of-the-art guidelines for long-term success in the use of gamification include the following drivers of success: (a) clear goals and rules, (b) transparency of information, (c) quick feedback on success/failure, (d) freedom of choice, © solvable, varied challenges, as well as (f) voluntariness. A comprehensive step-by-step implementation guide for the use of serious games in teaching is depicted in Figure 12.

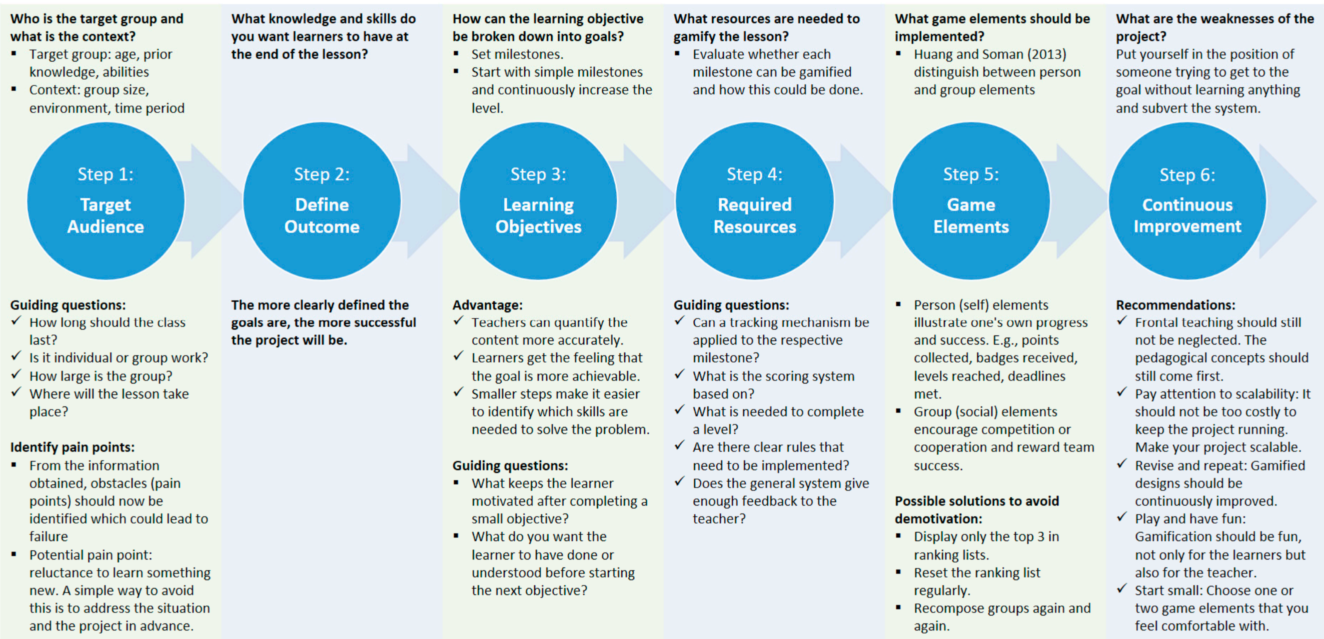


Figure 12. Step-by-step implementation guide for the use of serious games in teaching, graphical depiction by the authors summarizing methodology by [90].

5.7. What Are the Criticisms of Gamification?

A common criticism is that gamification manipulates rather than motivates [91]. The main argument here is that intrinsic motivation is not addressed by gamification. Moreover, purely extrinsic motivation leads to a focus and reduction on a specific goal and thus prevents explorative behaviour that maximises learning progress. Successful gamification therefore combines both extrinsic and intrinsic motivation of the players [92]. Ideally, gamification is not the mere addition of game elements with the aim of motivating someone. This approach would basically only address extrinsic motivation, which disappears over time. Consequently, if only reward mechanisms are used, intrinsic motivation decreases. Empirically, this can be explained by the fact that a fixation on rewards reduces the brain's cognitive performance. Reward elements should therefore, if possible, only be used as a feedback system and not be the focus of the learning experience [93]. In games, the reward received is therefore also always the beginning of a new task and not its end. Furthermore, learners should be given the freedom to develop their own ideas and solution approaches in the game [94].

Another important criticism often mentioned in the literature is that learners are demotivated by comparison with their competition [95]. Therefore, transparent performance comparisons, e.g., league tables, should be used with caution [96]. If they are nevertheless used, these tools should be reset in order to achieve a "level playing field" on a regular basis. Similarly, in group work, the composition of the teams should be changed regularly; this too enhances the learning experience through the variety of peer instruction teaching. Creative approaches to solving problems should be in the foreground. A quick achievement of the goal, on the other hand, should not be the focus. Ideally, game elements should be primarily used to illustrate one's own progress instead of comparing oneself with others.

Finally, the last but frequent criticism is that gamification leads to playing instead of working and thus to unproductivity [97–99]. Studies on learning efficiency clearly show that playing is by no means the opposite of working. It has been proven many times that productivity increases through the sensible use of gamification [100,101]. Success depends above all on the technical sophistication and target group appropriateness of the game used. Targeting is therefore essential, which [82] (p. 27) also empirically confirms: *"The real truth is that any tool or technology that is not designed properly or wholeheartedly will not be effective"*.

5.8. What Kind of Game Elements Are There and What Are Their Effects?

According to [102] specific game elements are vital to ensure a satisfying gamification experience. We will discuss the main elements and their characteristics as follows:

The heroic journey or the quest: A quest is comparable to a mission that must be completed in order to gain experience points or reach a higher level. Some quests must be completed within a certain time, others require teamwork. Depending on the structure of the task, the players practise organising themselves in teams or finding solutions independently. Experience points or other positive feedback is given for solving the task. The choices make the game exciting and let the learners be creative [103].

The power of narrative or storytelling: Computer games usually tell a story, which is sometimes more, sometimes less in the foreground. The players are involved in the story and have a task to fulfil. To impart knowledge effectively, a story must be spun around the new topic or lesson. As in role-playing or adventure games, learners have certain tasks to complete that fit the story. The content of the tasks and the lesson material should be based on this story. For more mature learners, it is advisable to make the story realistic and relevant [104].

The whole is greater than the sum of its parts or epic significance: When the game makes the participants feel like they are a significant part of a larger whole, this is called epic significance, especially in role-playing games. For example, in a team task, it may be a condition for solving the task that all learners are involved in the solution [105].

Experience points: Experience points are gained by solving challenging tasks. The points give learners immediate feedback on where they are at the moment. Experience points are the foundation of competency-based learning [106] and refer to systems for teaching, assessment, grading and academic reporting that are based on learners demonstrating that they have acquired the knowledge and skills they are expected to learn during their education [106].

Levels: The levels represent different degrees of difficulty or required skills in the game. The higher the level, the more difficult it is. Stronger learners master the easy levels quickly. Those who are not yet as good have the opportunity to improve slowly before moving up to the next level [107]. Since high-performing players finish faster, diligence tasks can be provided, with which they can win special awards, for example.

Badges (awards and titles): Those who have solved a task particularly quickly or with a particularly good result, helped other players or solved many puzzles receive an award. The award is feedback for the learner and motivates to collect even more awards [102].

Progress bars: A progress bar is a graphical control element used to visualize the progression of a gamer in the gaming process. Progress bars [108] are used to show players how much they have achieved and how far they are from the goal.

Leaderboards: Rankings or leaderboards are large digital boards for displaying the ranking of the players in a competitive game. Leaderboards are used to encourage competition by comparing oneself with the performance of other players [109,110]. However, in the context of teaching, it is recommended not to use this element as it can be perceived as demotivating by weaker learners [109,110].

5.9. Serious Games—Technological Outlook and Stocktake of Available Learning Games

Digital twins are increasingly used in industry applications and are predestined for becoming part of the metaverse [111], which has been heralded as the next generation of the Internet. Although it lacks a common definition, gaming is already a key component of emerging metaverse platforms, like the *Roblox* and *VoRtex* gaming platforms [112–114]. Therefore, gamified engineering curricular, as presented above, could further develop into engineering metaverses [115]. An engineering metaverse would manifest as a shared space where augmented, virtual and physical realities converge. The user—who will be a learner, facilitator, consumer, and producer—will interact with the metaverse in real-time and permanently with a deeper sense of immersion. Human users and their virtual avatars will come together not just to learn, but also to work and socialise with a deeper sense of immersion. Such engineering metaverse will have the potential to become a user-generated-content-platform that enables direct interaction within the context of smart cities and operational cyber-physical infrastructure, thereby further blurring the traditional boundaries between learning and doing, theory and practice [116].

A selection of available gamification programs and serious games and their short description are summarized in Table 2.

Table 2. Select examples of available gamification programs and serious games (all listed websites have been accessed in 31 July 2022).

Name	**Topic**	**Description**	**Cost**	**Number of players**	**Platform**
Anne Frank House https://annefrankhousevr.com/	History, VR	*Immerse yourself in Anne's thoughts as you traverse each faithfully recreated room, fully restored thanks to the power of VR, and find out what happened to the Annex' brave inhabitants.*	Free of charge	1	Gear VR, Oculus Go
Brilliant https://brilliant.org/educators/	Mathematics, Technology, Computer Science	*Brilliant replaces lecture videos with hands-on, interactive problem solving. It's a better (and more fun) way to learn.*	Free of charge	1	Browser, iOS, Android
Change Game https://www.changegame.org/	Politics, Climate, Economy	*Build a city in an urban, rural, mountain, coastal or island environment; Bring in power and water; Build manufacturing and service industries; Manage resources, trade them with other players; Invest in research, education and entertainment; Care for the health, happiness and prosperity of the community.*	Free of charge	Up to 30 players	Android, iOS
Climate Adaptation Game https://www.smhi.se/en/climate/education/adaptation-game-1.153788	Economy, Politics, Climate	*The Climate Adaptation Game increases the understanding of what a warmer climate implicates and how we can adapt to it. The game is suitable for education in sustainable development and when starting to work with climate adaptation.*	Free of charge	1	Browser

Table 2. *Cont.*

Name	Topic	Description	Cost	Number of players	Platform
Climate Adaptation Game https://www.smhi.se/en/climate/education/climate-adaptation-game	Climate	*The Climate Adaptation Game increases the understanding of what a warmer climate implicates and how we can adapt to it.*	Free of charge	1	Browser
Climate Quest https://earthgames.org/games/climatequest/	Climate	*Climate disasters are occurring across the United States, but your 4 heroes have the skills to save countless lives and protect fragile ecosystems! Forecasts of climate disruptions appear all across the map, each based on real impacts selected from the US National Climate Assessment.*	Free of charge	1	Browser, iOS, Android
Climate Trail https://www.theclimatetrail.com/	Climate	*The game is about climate refugees fleeing ever worsening conditions after inaction on climate has rendered much of the USA (and the world) uninhabitable. The game combines the adventure and play of the journey north with visual novel elements, where characters reveal how and why this climate apocalypse unfolded.*	Free of charge	1	Windows, OSX, Linux, Android, iOS
Codewars https://www.codewars.com/	Computer Science	*Problem solving with achievements. Very successful for gamification.*	Free of charge	1	Browser
Datacamp https://www.datacamp.com/?irclickid=Q2ExXOwNrxyIR811SZ0SoyHbUkG21kzRFVtdV00&irgwc=1	Computer Science	*Learn the data skills you need online at your own pace—from non-coding essentials to data science and machine learning.*	Free of charge	1	Browser
Duolingo https://www.duolingo.com/	Language	*Gamified language learning.*	Free of charge	1	Android, iOS, Browser
Escape Climate Change https://www.escape-climate-change.de/home.html	Climate	*Escape Climate Change is an interactive game that approaches the topic of "climate protection" with fun and excitement. The concept is based on the idea of the Escape Game, in which a small group must succeed in solving a complex puzzle in a given time. The game is aimed at pupils at secondary level I and II.*	Free of charge	Multiplayer	Browser
Google Earth VR https://arvr.google.com/earth/	Geography, Architecture, VR	*Explore the world from totally new perspectives. Stroll the streets of Tokyo, soar over Yosemite, or teleport across the globe.*	Free of charge	1	Oculus Rift, HTC Vive
InMind 2 https://luden.io/inmind2/	Biology, Soft Skills, VR	*InMind 2 is an adventure game which places emphasis on the chemistry behind human emotion, greatly inspired by the Pixar/Disney movie "Inside Out" and (more scientifically) Lövheim's theory of emotions.*	User fee	1	Windows, Linux, Android, iOS, Gear VR
Level Up! https://moodle.org/plugins/block_xp	Moodle	*Moodle plugin to introduce levels.*	Free of charge	1	Browser
Lost in Antarctica https://seriousgame-lia.wi2.phil.tu-bs.de/	Soft skills	*Lost in Antarctica is a point-and-click browser game for learning information literacy. Skills such as researching, citing or scientific writing are learned and practically applied in a playful way embedded in a fictitious research expedition at the South Pole in twelve levels.*	Not known	1	Browser
Lost in Translation https://softskillspills.com/lost-in-translation/	Communication, soft skills	*A game with real situations, which are very close to everyday life, show you how some things appear clear at first glance, but are in fact unclear.*	Free of charge	1	Browser
Minecraft Education Edition https://education.minecraft.net/en-us/homepage	Gamification	*Minecraft platform, variable use for gamification*	User fee	Multiplayer	Windows, OSX
Mission 1,5 Grad https://mission1point5.org/	Climate, strategy game	*Using mobile gaming technology, Mission 1.5 educates people about climate solutions and asks them to vote on the actions that they want to see happen. What will we do with the results? Your vote, and those from your country, will be compiled and presented to your government to encourage bolder climate action. Votes will also be counted in a global tally. So stay tuned for the results!*	Free of charge	1	Browser

Table 2. *Cont.*

Name	Topic	Description	Cost	Number of players	Platform
Peak https://www.peak.net/	Brain jogging	*Discover what you can do with Peak, the number 1 app to challenge your brain. Push your cognitive skills, train harder and use your time better with fun, stimulating games and workouts.*	Free of charge, full version 100€	1	iOS, Android
Phet https://phet.colorado.edu/	Maths, Physics	*Simulations for STEM concepts*	Free of charge	1	Browser
Quizlet https://quizlet.com/de	Gamification	*Playfully learn flashcards and measure skills with fellow students.*	User fee	Multiplayer	Browser, iOS, Android
Reality Check https://mediasmarts.ca/digital-media-literacy/educational-games/reality-check-game	Soft skills, critical thinking	*Because fact-checking shouldn't be a chore, each scenario is designed to be played in 15 min or less. The game can be played in any internet browser on computers or mobile devices.*	Free of charge	1	Browser
Slidesmania https://slidesmania.com/	Gamification, Quiz	*"Gameshow" Quiz PowerPoint Templates.*	Free of charge	1	Browser
SQL Murder Mystery https://mystery.knightlab.com/	Computer Science	*Playfulracticinging SQL. You have to know SQL.*	Free of charge	1	Browser
Top Hat https://tophat.com/	Gamification	*Gamification Plattform.*	User fee	Multiplayer	Browser
Typing Club https://www.typingclub.com/	Soft Skills, Typing	*A game with which you can learn the 10 finger system.*	Free of charge	1	Browser
Tyto Ecology https://www.tytoonline.com/	Biology	*Build your biome! With an empty biodome as your canvas, add plants and animals from three different ecosystems. Observe interactions like hunting, blooming, and even decomposing! Will your biodome last for decades, or will it experience a total ecosystem collapse? You're in control!*	User fee	1	Windows, OSX
VIM Adventures https://vim-adventures.com/	Computer science, soft skills	*An adventure game to learn the VIM editor controls.*	User fee	1	Browser
https://seriousgames-portal.org/#GamePage/df9128e5-abd9-47a8-a089-491fc853a415	Economy, Politics	*In Virtual Cities, an economic cycle is played out.*	Free of charge	Multiplayer	Browser

6. Adopting Novel Approaches in Engineering Education

Today, leaders in engineering education agree that fostering students' cognitive and intellectual skills is one of the most important tasks of engineering education. These skills strengthen students' perceptions of the world and the resulting decisions they make. In particular, critical thinking is central to both personal development and the needs of society [117]. Engineering students' ability to master good reasoning for problem solving can be fostered through a didactic process directly aimed at developing students' critical thinking skills [118].

According to a recent study [119] on "the global state of the art in engineering education" conducted by the Massachusetts Institute of Technology's ("MIT") New Engineering Education Transformation ("NEET") initiative [120], a range of key barriers continue to constrain positive change in engineering education worldwide including but not limited to (a) misalignment of government and higher education goals, (b) failure to deliver student-centred active learning [119,121] to large student cohorts, (c) siloed monodisciplinary structure of many engineering schools, and (d) faculty appointment and promotion systems that are not perceived as rewarding teaching achievements [119].

However, some positive developments in changing the direction of the engineering education sector can be observed. In this context, the NEET study identified a set of current and emerging education institutions that demonstrate good educational practices including (a) user-centred design, (b) technology-driven entrepreneurship, (c) active project-based learning, and (d) focus on rigor in the engineering fundamentals.

A group of current and emerging institutions in engineering education introduced a new generation of engineering programmes, many of which were developed from a blank slate or the product of systemic educational reform, and which were often shaped by competitive pressure as well as specific regional needs and constraints. Distinctive educational features of these leading programmes include work-based learning, multidisciplinary programmes and a dual emphasis on engineering design and student self-reflection. The study suggests that the novel programs have benefitted from strong and visionary academic leadership, a faculty culture of educational innovation and new tools that support educational exploration and student assessment. As a key takeaway of the NEET study, most successful engineering programmes move towards socially relevant and outward-facing engineering curricula. Such curricula emphasize student choice, multidisciplinary learning and societal impact, coupled with a breadth of student experience outside the classroom, outside traditional engineering disciplines and across the world. Novel approaches of engineering education deliver distinctive, student-centred curricular experiences within an integrated and unified educational approach. Progressive curricula, for instance of Olin College of Engineering [122] or Iron Range Engineering [123], had been designed from scratch and followed an integral reform approach. Hands-on experiences such as work-based learning and societally relevant design projects are embedded into the programmes in a way that provides a solid platform for student self-reflection and a pathway for students to both contextualize and apply the knowledge and skills they have gained elsewhere in the curriculum. Clearly, a new generation of leaders in engineering education is currently emerging delivering integrated student-centred curricula at scale that include multidisciplinary design projects, which contextualize and integrate learning across courses and years of study. Students are being put at the centre and use the resources to facilitate team projects and authentic experiences, subsequently the taught curriculum is put online. As a result, almost all technical engineering content—including both knowledge and skills—is delivered online and accessed independently by students, as and when they need it. This new approach is described as "*completely rethinking what engineering education ought to look like*" with the potential to be "*very influential, if they can pull it off.*" [124,125].

In summary, bold new methodologies that most effectively connect science and technology to real-life situations using active learning pedagogies need to be emphasized more in engineering classrooms. Discussions have revolved around project-based learning, case-based learning, discovery learning, and just-in-time teaching with three instructional approaches of active learning, cooperative learning, and problem-based learning [126]. The benefits of using these progressive approaches are improved retention of knowledge, better reasoning and analytical skills, development of higher-order skills, greater ability to identify relevant issues and recognize multiple perspectives, higher motivation and awareness of non-technical issues. Many of these outcomes are part of the expected attributes of civil engineers outlined by professional bodies [127].

Learner-centred pedagogies, such as the case method or Socratic inquiry, hybrid e-learning [128] make material more relevant and increases motivation for students [129,130]. The traditional method of instruction, lecture based, does not appeal to today's scholar and does not provide adequate training as needed for professional development and readiness. A meta-analysis of 225 studies shows that active learning clearly leads to increases in examination performance (Figure 13). The students who encounter material delivered via the case method are more likely to grow and grasp the conceptual understanding of a topic than those who sit through a traditional lecture.

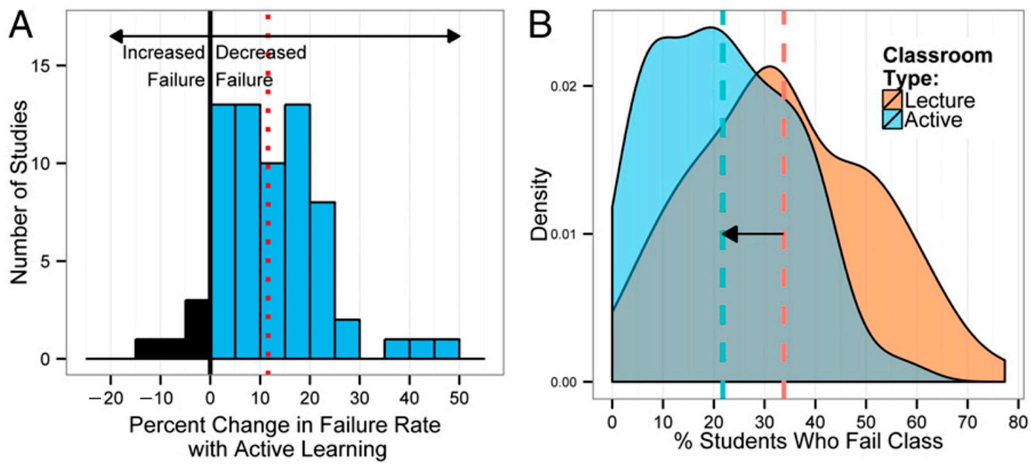


Figure 13. A meta−analysis [131] of 225 studies shows that active learning leads to increases in examination performance, e.g., changes in failure rate. (**A**) Data plotted as percent change in failure rate in the same course, under active learning versus lecturing. The mean change (12%) is indicated by the dashed vertical line. (**B**) Kernel density plots of failure rates under active learning and under lecturing. The mean failure rates under each classroom type (21.8% and 33.8%) are shown by dashed vertical lines (Reprinted with permission from the author [131]).

The case method promotes authentic situations and embedded scenarios that the students learn in the confines of the institution further bridging the gap between theory and application. The preparation of the engineering student is achieved by student centred active learning by focusing on the case study and apprenticeship pedagogical methods. This will allow us to link technical content with applied knowledge and experiences [132]. Business and engineering case studies have been found to increase students' critical thinking and problem—solving skills, higher—order thinking skills, conceptual change, and their motivation to learn. Results suggest that participants felt the use of case studies was engaging and added a lot of realism to the class making the content more relevant to students. Case-based instruction can be beneficial for students in terms of actively engaging them and allowing them to see the application and/or relevance of engineering to the real world [129]. At St. John's [133], for instance, you will not find 100-person lectures, teaching assistants or multiple-choice tests. Instead, classes are led by tutors who guide students through a Socratic inquiry. Despite its reputation as a merciless exercise in student humiliation, the Socratic method is an interactive form of intellectual sandpapering that smooths out hypotheses and eliminates weak ideas through group discourse. Tutors lead St. John's discussions but rarely dominate; they are more like conversation facilitators, believing that everyone in class is a teacher, everyone a learner [134]. The Socratic inquiry prepares engineering students to become excellent communicators better navigating an increasingly complex multistakeholder ecosystem.

The Fourth Industrial Revolution requires the education sector to reform the entire education process and align it more synchronously with future needs so that students can interact smoothly with the revolutionary, exponential changes. In this context, e-learning in particular will play a major role, as networking and thus scalability will create a healthy competition of the best content and the most sophisticated didactics. However, also through e-learning collaborations, there are numerous opportunities for educational institutions, especially higher educational institutions, to work, collaborate and help each other within the e-learning platform [135].

7. Mitigating the Disruptions during the Transition

While a new engineering curriculum and education system as highlighted above will prepare workers for the 4IR, the time needed for the implementation of such system can well be accompanied by the disruptions caused by the 4IR, including increased unemployment and underemployment one the one hand, and labour and skill shortages on the other. However, as recent empirical study, which has been carried out by the University of Cambridge, suggests that with the right labour policies the massive boosts in productivity made possible by 4IR technologies could mitigate the disruptive effects and even enhance the quality of life by reducing hours of work instead of making worker redundant. The study highlights that the reduction in working hours for full-time workers can be an alternative to conventional labour policies, thus offering the potential to reap the full benefits of the next technological revolution. In terms of occupational health, the study found that working one day per week or five days per week does not make a difference in terms of occupational health. Instead of unemployment or granting universal basic income, working time reduction could lead to a number of benefits for individuals, their families and their societies, and provide the necessary time for reskilling and for labour markets to adopt to the requirement of the 4IR [136].

8. Conclusions

If we proceed business-as-usual, we will prolong the social pain, and thus teachers will be at risk. AI will enable effective personalized student learning and, therefore, will be essential to future university success. Teachers will be social facilitators but will also program and train AI. The exponential technology combined with fundamental hard skills, including first principles thinking and soft skills such as empathy, creativity, communication, and collaboration, will play a key role in future-ready curricula.

The global engineering community is starting to rethink extensively how to best prepare the engineers of tomorrow. To future-proof the profession, engineers must be prepared with a broader and deeper vision [19] that embraces the challenges and complexities of the 4IR. As a community, we urgently need to develop a blueprint for shaping the future of the engineering profession by taking a holistic systems view. This vision needs to influence how we educate the next generation of engineers as well as how we build, maintain and increase an interactive body of knowledge and methodologies in light of the 4IR with AI as a mentor and partner in knowledge generation and dissemination. The role of teachers soon may be passed to virtual tutors. The role of gaming environments and augmented reality in educational activities is growing. According to forecasts [137], games and teamwork will become the dominant forms of education and social life by 2035. Another direction of education development is strengthening its project nature, blurring the distinction between traditional technical and humanitarian education. This requires the creation of new interdisciplinary courses, the revision of the classical approaches to engineering and humanitarian education [26]. Rethinking the engineering profession will in turn shape the service to society and consequently can enhance the welfare of humanity.

By setting out a bold vision and creating a culture that is undaunted by tradition, Elon Musk and other successful innovators manage to attract the best talent from very different fields and to defy standard industry practice. Culture is a talent magnet, and education institutions as well as companies need to implement a culture that challenges the status quo and embraces innovation wholeheartedly. The widespread adoption of game-changing innovations that consider a variety of possible futures is going to make a serious impact, socially, economically and environmentally.

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