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Participant No *	Participant organisation name	Acronym	Country
1 (Coordinator)	University POLITEHNICA of Bucharest	UPB	RO
2	Universidade NOVA de Lisboa	NOVA	PT
3	Universita Politecnica delle Marche	UPM	IT
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Table of Contents

1 Introduction 4

2 History and Direction 5

2.1 History 5

2.2 Direction 6

2.3 From Offline to Online Teaching and Back 7

3 MOOCs 10

3.1 Why MOOCs Are Not Game Changers for Education Yet 13

3.2 MOOCs vs. Online Courses vs. Traditional Teaching 16

3.3 Learning from the MOOC Business Models 19

4 Research-Based Learning 24

5 Digital and Virtual Labs 28

5.1 Digital Labs 28

5.2 Virtual Labs 30

6 Future Learning 33

6.1 The Distributed Classroom 36

6.2 Education 4.0 38

Bibliography 41

1 Introduction

The COVID-19 pandemic has brought significant changes to the field of education, with a shift towards online learning. This shift was initially thought to be temporary but has since become permanent, or at least sparked a revolution in education. Previously, education was focused on transmitting information to students to be memorized and reproduced, but experts now believe that the future of education should involve a combination of classical intelligence, resilience, and emotional intelligence. This new model of education will be aided by the combination of traditional face-to-face learning and online learning, as students have been shown to learn more efficiently online by being able to maintain their own pace throughout the learning process.

The debate between traditional and online learning (or eLearning) has been ongoing for over a decade, but has become more prominent due to the pandemic, as people of all ages have been forced to adapt to alternative methods of learning online. This has led to the development of various eLearning tools to cater to different types of students and courses, including Massive Open Online Courses (MOOCs), offered by platforms such as Coursera, edX, and Udacity. However, MOOCs are limited by their cost and availability only to wealthy institutions, as well as the high rate of students who start but do not finish the course.

Research-Based Learning (RBL) has also become more popular, combining classroom teaching with research methodologies, encouraging students to find their own way to conclusions to develop critical thinking, analysis, argumentation, and the ability to sift through sources. RBL has gained popularity during the pandemic as it reduces the need for step-by-step guidance from teachers.

One recent tool introduced is the digital lab, which allows students to recreate experiments through advanced simulations and interactively collect, process, and analyze data, drawing conclusions about the results. This has evolved into virtual labs, offering advanced virtualization of laboratories that can be accessed remotely, providing students with the closest experience to being physically present in a lab without actually being there, particularly useful for students who do not have access to labs at their universities or are unable to be physically present due to circumstances like the COVID-19 pandemic.

This report delves into the distributed classroom paradigm in the context of the LLSF project with Education 4.0, taking advantage of the methods mentioned above.

2 History and Direction

2.1 History

Various experts around the world agree that universities will not return to the way they behaved before the COVID-19 pandemic [1]. Before that, many people promoted the need for change in academia, mainly due to factors such as declining birth rates and political support for vocational education. However, no one predicted the critical issues we remained with in the aftermath of the pandemic. People have grown accustomed and adapted to staying indoors, and thus a multitude of alternative sources of information have become widely available, such as YouTube, podcasts, massive open online courses (MOOCs), etc. Coming soon, there will be a metaverse model that offers immersive experiences through headphones and smart glasses. Coupled with 5G (and, before long, 6G), we can imagine a metaverse-based 3D virtual university. Machine learning (ML), though still relatively novel, has an immense potential, including making thousands of high-end jobs obsolete, and thus affecting new graduates. Furthermore, robotic process automation similarly affects lower-end jobs. Moreover, in the last 10 years we have borne witness to students being disengaged from universities, a situation exhibited by the reduced participation in classes and increased viewing of higher-speed recordings right before exams [1].

Universities have been in a similar position before, and this is something that we can and should learn from. Around the 1800s, people were asking what the point of universities was, since lectures were considered boring: the professor simply sat in a chair and read the text, sometimes very slowly so that students could decipher and write it down. However, in the same period there was a boom of knowledge around the universities, and, in a short time, the number of printed books doubled, leading to the founding of scientific journals and the growth of encyclopedias, with major scientific discoveries resulting not from universities, but academies and research institutions [1].

The “revolution” started in 1810 in Berlin, where a specialization of knowledge in disciplines occurred, leading to rigorous sets of methodology and conventions reflected in the birth of new departments in higher education institutions. New types of lectures appeared, synthesizing and adding value to information that could simply be read from a book. Lectures now gave way to meaning, and in a decade a new type of seminar was born, one which encouraged students to debate and create by themselves, which ended up being used in most of Germany in less than 10 years [1].

The parallel above is meant to show that we might be part of a similar epistemic authority crisis, accelerated by the pandemic, but caused not only by elements such as YouTube videos, Wikipedia,

MOOCs, podcasts, etc., but also by artificial intelligence (AI) and machine learning, which are already able to extract meaning from large amounts of data, which was the initial purpose of teaching and learning.

However, the solution is not to simply return to the pre-pandemic way of teaching, but to use technology to help strengthen the differences between universities and tech giants, instead of blurring them, helping humans maintain an advantage over machines and algorithms and allowing us to learn what ML and AI cannot do or understand, such as practical wisdom [1]. We can envision the campus of a university like a hub (similar to the cathedrals of old), where people come together to create connections, help each other learn and understand, and ultimately become better human beings. Continued work is indeed needed on business and operating models, but a major intellectual rethink of how universities will maintain their unique trust is at least as important.

2.2 Direction

In a period when good education is more important than ever to a person's life chances, children who need to be in school are not, missing on opportunities to fulfill their lives as adults and contribute to the world economy. It seems that education is losing its value in an era of innovation, disruption and constant change, where adaptation and learning are most necessary [2].

According to psychologists, there are four types of human intelligence: Intellectual Quotient (IQ), Emotional Quotient (EQ), Social Quotient (SQ), and Adversity Quotient (AQ) [3]. The intelligence quotient (IQ) is a measure of intelligence, useful for solving math problems, memorizing things, and remembering lessons learned. The emotional quotient (EQ) is a measure of a person's ability to be at peace with others, be punctual, be honest, show integrity, be respectful of others, exhibit humility, honesty, and consideration. The social quotient (SQ) is a measure of a person's ability to form a social network of friends and keep it over time. People with high EQ and SQ are more likely to get ahead in life than people with high IQ and low EQ and SQ.

The current education system places a heavy emphasis on IQ, especially in terms of memory and planning, which will be easily and effectively replaced by AI in the future, if that has not already happened. Thus, someone with a high IQ may end up being hired by someone with high EQ and SQ, and an average IQ. EQ represents a person's personality, while SQ represents their charisma. We believe that education should focus on improving these three Qs, especially EQ and SQ.

However, more recently a fourth type of human intelligence has been defined, the adversity quotient (AQ). It is a measure of a person's ability to navigate difficult situations in life and get out of them without losing their sanity. Accordingly, people define a fifth type of intelligence, Resilience (RQ), as the ability to continue. In the face of adversity, RQ decides who will give up, who will abandon their family, and who will consider suicide. We believe that we need to expose students to areas of life such as manual labor (but not as punishment), sports, and arts. A good mix of IQ (intelligence) and EQ (emotional quotient) as well as RQ (resilience) is important to fulfill a student's potential, but currently most education institutions place emphasis on IQ improvement, while EQ, AQ, RQ and SQ play lesser roles.

An evaluation of the current education system based on three criteria (job readiness, ability to compete with intelligent machines for work, and long-term economic value) described in [2] showed that 34% of students believe that their education does not prepare them for success on the labor market (so the link between education and employability should be strengthened), while also highlighting that 60% of the jobs of the future have yet to be developed and 40% of kindergarten students in today's schools will need to be self-employed [4] (so students need to be prepared for jobs that do not yet exist, or for entrepreneurship).

Research has also shown that universities undervalue critical thinking [5]. Thus, they often teach subjects that differ from the thinking that students need to do if they are to master that subject. For example, they learn math, they don't think mathematically. Students are expected to conduct research but universities have no clear idea of how to teach students the means of that analysis. They cannot explain the intellectual characteristics (conditions) associated with intellectual discipline. They do not have a clear idea of the relationship between critical thinking and creativity, problem solving, decision making or communication. They often don't realize that formal education doesn't work well. They lack the classroom instructional strategies that aid students to master the content and become effective learners. Many education institutions have these problems, but few are aware of them. On the other hand, critical thinkers carefully study how people form, develop and use ideas [5], and we believe that this is how future students should be.

At the same time, technological advances are considered a good addition to today's classroom [6]. Using technology, such as online learning, in higher education learning should include improving student thinking. For example, using digital learning platforms such as Moodle can help students develop their reasoning, problem-solving and decision-making skills. In addition, the combination of critical thinking and online activities (such as asynchronous online discussions) can be a chance for students to increase their interest and achieve a higher level of knowledge. In what follows, we discuss the advances and challenges for educational practitioners in bringing critical thinking concepts and their implementation to synchronous online learning.

2.3 From Offline to Online Teaching and Back

In the past decade, there has been an ever-growing debate between traditional learning and eLearning, which was further accentuated by the COVID-19 pandemic and the following years, when an extremely high number of people participated in remote learning. According to statistics [7], approximately 70% of the world's total student population was affected by school closures due to the COVID-19 pandemic in 2020. This has led in turn to the accelerated growth of the global eLearning market, both in terms of business, as well as importance. Therefore, we believe that it is important to highlight the similarities and differences between traditional learning and eLearning.

Traditional learning generally involves a central focal point of the students' attention, namely the teacher that interacts directly with student groups in a well-defined physical space such as a classroom or an amphitheatre, for a specific period of time. The focus is generally on a single particular topic, be it theoretical or practical. The curriculum and courses are generally based on standardized, governmentapproved textbooks used by both teachers and students.

Although the trend seems to be moving away from traditional learning, it has several important advantages. Firstly, there is the social dimension given by face-to-face learning, which allows students and teachers to get to

know each other better. Non-verbal communication can thus occur between the participants, which can often be overlooked in an online environment and thus lead to a more difficult interaction. Moreover, there is a certain discipline that is brought by having a daily routine, which can help students (especially younger ones) improve their organizational skills. Additionally, traditional face-to-face learning allows teachers to show hands-on examples that students can touch and interact with.

However, there are naturally some drawbacks to traditional learning. One example is that some students (and even educators) may find it difficult to maintain the institution's demanding schedule when they have a job or other obligations. The commute between home and school can take a lot of time, and it can also be expensive in terms of money spent on gas or public transportation tickets. Furthermore, traditional learning also comes with higher costs in terms of tuition, accommodation, etc. Last but not least, giving a lecture in front of a high number of students can lead to their loss of attention of focus (and thus to passive listening), especially if the level of the students is not uniform [7].

In contrast, eLearning is defined as education that happens online. In eLearning, educators typically upload customized content to a learning management software (LMS) and share it digitally with the students. Learning content can thus be accessed anytime, from anywhere there is a Internet-connected device, which means that students do not all have to be physically in the same location in order to take the same class. Although some LMSs offer a live online stream where students can communicate with their educators in a live environment, in many cases students do not even interact directly with their teachers, since many LMSs only offer chat rooms, forums, or email.

A large part of the eLearning industry is oriented towards professionals who want to further their education or change careers entirely. Because of this (and especially after the pandemic made some people rethink their lives or careers), there is a growing business ecosystem of commercial LMSs such as Coursera, edX, Udacity, or Skillshare. To further blur the lines between traditional and eLearning, a growing number of higher-education institutions offer undergraduate, graduate, and doctoral-level courses entirely online [7].

Nonetheless, eLearning has several advantages, the first being that participants can access learning materials at their convenience, while the educator can also control when and at what pace students view and access content. Another advantage is that students can collaborate through the help of an LMS and its features (such as forums, chat rooms, etc.). Furthermore, eLearning is done in a modern medium which takes advantage of the fact that many students already spend most of their day on their laptops, tablets, or smartphones, being constantly connected to the Internet.

However, there are naturally some disadvantages to eLearning as well, one of them being that there is a need for community building among the students if we want to fulfill the maximum potential of collective learning (which, as previously stated, is something that comes naturally in face-to-face learning). Another disadvantage is that some online instructors may not always utilize all the features of an LMS, but instead they try to replicate traditional teaching in an LMS, which is generally not suitable without a degree of adaptation. In terms of monitoring and maintaining student concentration, it can be very difficult for educators to get students to concentrate for long periods of time if they are not in the same room as them. For online educators, it can be difficult to monitor learners and determine exactly who is engaging and fully participating in class [7].

While remote or eLearning offers students a high degree of flexibility and the ability to study on-demand, higher education institutions offering eLearning courses are also gaining recognition in new markets and countries. Many online learning platforms have stepped up their services during the pandemic. For example, Lark, a collaboration suite based in Singapore, which was originally developed by ByteDance as an internal tool to keep

up with its own exponential growth, offers teachers and students unlimited video conferencing hours, automatic translation capabilities, as well as real-time collaborative editing of projects, and features such as smart calendar scheduling [8]. For this, Lark leveraged its global server infrastructure and engineering capabilities to ensure reliable connectivity. DingTalk, Alibaba's distance learning solution, had to prepare for a similar influx. To support remote work at scale, the platform leveraged the Alibaba Cloud to deploy over 100,000 new cloud servers in just a few hours [9]. Technology is therefore aiding the shift to an online approach to learning, but learning methods need to be re-adapted to online-based student interactions.

However, there are still additional challenges. For example, students may struggle to be a part of digital learning when they do not have access to a reliable Internet connection or the required technology. These differences can be observed by country and by income group within a country. For example, according to OECD data [10], 95% of students in Switzerland, Norway and Austria use computers for schoolwork, whereas only 34% of students in Indonesia do. In the United States, there is a big gap between the advantaged and the disadvantaged. Nearly all of her 15-year-olds from privileged backgrounds said they had access to computers, while about 25% of those from disadvantaged backgrounds stated that they did not have access or the means to use a computer. It is true that there are learning institutions and governments that are providing digital devices to those that require them (like Australia's New South Wales [11]), but there is still a growing concern that the pandemic will widen the digital divide.

It was shown that online learning can be more effective for those who have access to the appropriate technology, since they can retain 25-60% more on average when online, as opposed to 8-10% when attending classes physically [12]. This is mainly because students can learn faster online, since they can study at their own pace, go back and repeat, skip concepts or jump around at will [13]. However, the interesting question being asked right now is which of the two learning methods (classic in-person learning or eLearning) is the future. The pandemic has completely disrupted the education system, but many were already arguing that was losing its relevance [2]. In "21 Lessons for the 21st Century" [14], Yuval Noah Harari argues that traditional academic skills and memorization are still emphasized by education institutions, rather than skills like critical thinking and adaptability [15]. It seems that the future will shift to online learning in order to create new, more effective ways of educating students, making eLearning part of the norm, rather than an exception brought about by extraordinary circumstances [16].

3 MOOCs

Massive Open Online Courses, or MOOCs, utilize the internet to offer free online courses to anyone who wants to enroll [17]. They provide an affordable and convenient way to gain new skills, advance in one's career, and provide quality educational opportunities on a large scale. People from all over the world use MOOCs for various reasons, including career development, career changes, college preparation, additional learning, lifelong learning, corporate training, and more. MOOCs first gained popularity in 2012, when three influential platforms (Coursera, edX, and Udacity) were established. Many prestigious universities collaborated with these platforms to share their high-quality educational resources with the world. Since then, MOOCs have evolved and are now classified into two types: xMOOCs, which are more teacher-led, and cMOOCs, which are more social and non-hierarchical [18].

In 2013, Professor Fox at the University of California, Berkeley, introduced the concept of Small Private Online Courses (SPOCs), which are small-scale private online courses that are intended for university classrooms [19]. SPOC is considered a hybrid teaching mode that combines MOOC resources with traditional classroom teaching to maximize the benefits of both and improve the overall quality of education.

The rise of MOOCs in recent years has been a topic of much debate and is attracting increasing public attention, especially since the pandemic. MOOCs were created to meet the growing demand for lifelong learning, as more people sought education opportunities for personal enrichment and professional development in the face of rapidly evolving technological trends. As technology-based educational practices, MOOCs are gaining popularity in various fields, from business to colleges. However, some question if this form of open education adheres to traditional university principles. Regardless of the format, be it MOOC (such as Coursera), SPOC (with a Learning Management System like Moodle), or simply eLearning (such as Udemy), online learning is becoming a norm.

It is inevitable that online teaching materials will become a crucial part of education, and universities must find a way to incorporate this into their economic model. Improving the completion rate of MOOCs (which still remains an issue to this day) may require more guidance and mentorship, which should be considered in the workload of academic staff or delegated to Teaching Assistants.

In the future, it is believed that there will be an open standard for courses, where universities can build an online curriculum by selecting modules from a common database of online courses that adhere to common standards. Students will be able to earn their degrees incrementally and receive credits for each level. This flexible system will eliminate the need for fixed semester start and end dates, allowing

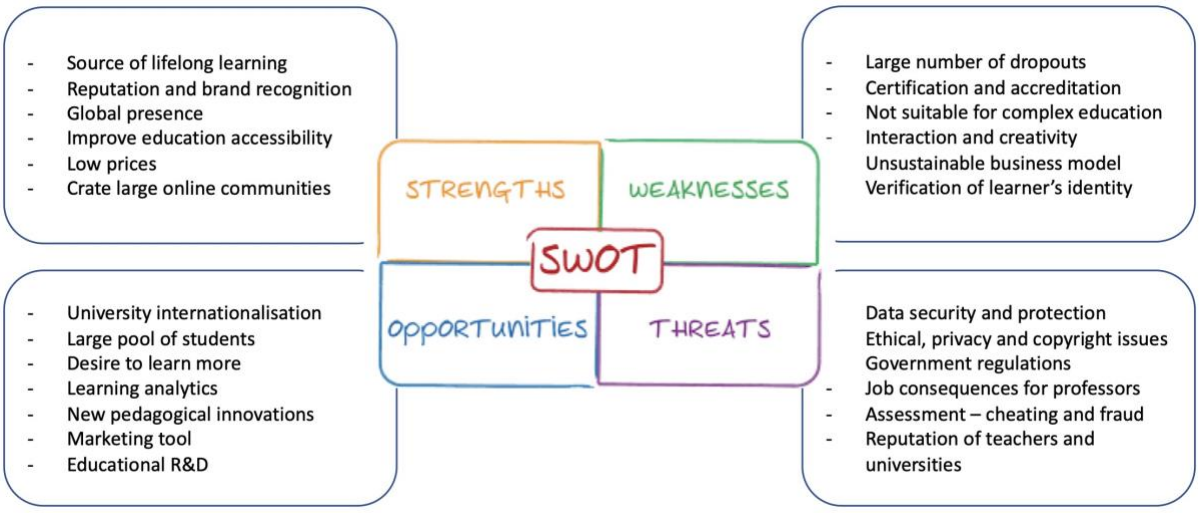

Figure 3.1: SWOT analysis of MOOCs.

students to complete their degrees at their own pace and from any location [20]. A unique student ID system will allow individuals to earn credits from various training institutions at any time, making it possible to reserve classroom sessions at a location near their home. This model is likely to result in academic institutions competing in a globalized marketplace.

The argument is supported by the SWOT analysis of MOOCs presented in Figure 3.1. The main requirement for participating in a MOOC is access to the Internet, and they have the capability to lead to increased global access to higher education. The growth in MOOCs has been substantial and is evidenced by the data and research attention in the field.

An example of the trend in MOOCs is the offering of credential and degree programs, such as edX's "Professional Education" courses and Kadenze's "Kadenze Programs". Coursera also introduced a pilot program in 2016 where all course materials, including videos, needed to be paid for, and launched "Coursera for Business" where companies could purchase content for their employees. Over time, Coursera has expanded to offer credentials and degree courses, resulting in a reported revenue of $140 million in 2018 [21].

Despite the growing popularity of MOOCs among educators and the public, there are some challenges that these online courses face [22]. One challenge is finding the best pedagogical approach to use in MOOCs. Another challenge is establishing a sustainable business model. MOOCs face weaknesses such as high dropout rates, lack of accreditation for certifications, difficulty in teaching complex subjects, limited interaction and creativity, and difficulty in verifying the identity of learners. The large enrollment numbers in MOOCs are offset by a high dropout rate, which may be due to the lack of social interaction and creativity in the course methodology. Additionally, certifications offered by MOOC companies are not recognized by quality assurance organizations.

Teaching complex subjects to thousands of students in a MOOC requires a significant amount of work from professors and teaching assistants, such as preparing laboratory experiments and workshops, and consulting with students. These demanding tasks raise questions about the suitability of MOOCs for complex education. Furthermore, MOOC platforms need to implement control mechanisms to verify the identity of learners. *In LLSF, we circumvent this by creating the first international online distributed learning platform that integrates Identity Provision through EduGAIN*. Formal exams

require a direct connection between the student and the examination process, which makes the institution responsible for awarding certificates only to those who actually take the exams. Coursera attempted to utilize biometric identification techniques, such as photos and text samples, to verify students, but with limited success. The issue here is managing and safeguarding biometric information while ensuring the privacy of individuals who provide it.

By creating MOOCs, universities have the potential to expand the reach and accessibility of their educational offerings globally. With the ability to build large online communities, MOOCs provide a wealth of data that can be beneficial for institutions in various ways. For example, early access to a global talent pool can assist employers in their recruitment process. Companies may also view MOOCs as cost-effective and flexible options for training their employees [22]. MOOCs can also enhance learning outcomes for higher education institutions through new pedagogical innovations and research. Advertisers can also benefit from these platforms, as learners spend a significant amount of time on them, leading to more clicks on ads. The collection and analysis of data about learning patterns and contexts, known as learning analytics, can help institutions identify and support various learner behaviors [22].

However, the growth and popularity of MOOCs bring up important ethical and privacy concerns such as the commercial exploitation of students and potential ethical issues arising from the analysis of their data by institutions and academics. The lack of quality and standards in MOOCs can also harm the reputation of universities and present a misleading view of MOOCs as the best eLearning option [22]. To address these concerns, new technological and policy solutions are needed to ensure the protection and security of student data, maintain anonymity, and prevent commercial exploitation. The challenge of maintaining proper copyright laws in a massive open environment like MOOCs is yet to be solved. The issue of effectively assessing student learning and preventing cheating in MOOCs remains a significant challenge that requires mature solutions to be developed.

With all these factors in mind, and based on the SWOT analysis in Figure 3.1, one may ask: why take a MOOC in 2022 [23]? MOOCs provide a one-of-a-kind experience for students, with some offering live instruction from real professors to a varying number of students, from 50,000 to just 1,000 who follow weekly learning modules. Despite the differences in enrollment, the accessibility offered by MOOCs makes them a powerful tool for reducing the gap in education and digital access across the world.

The reason for universities offering MOOCs is a topic of discussion given the availability of high-quality MOOCs on various online platforms, including Coursera, edX, Udacity, Udemy, Kadenze, etc. While some universities offer MOOCs as a way to attract potential students and incentivize them to enroll fulltime, others view them as a threat to their traditional source of income. The future of MOOCs in higher education is still unclear, with some experts predicting a surge in popularity that could change the way education is delivered. However, MOOCs also pose challenges for both students and educators, such as concerns over course quality and consistency, the presence of capable instructors, and the measurement of academic standards. Some also question whether online learning can truly be considered as learning and whether MOOCs can provide the same level of competence and skills as traditional education.

For those who want to expand their knowledge through MOOCs, these online courses offer a useful way to learn. They provide education to individuals who may not have access to it otherwise or who can't afford the cost of traditional higher education. MOOCs can complement university learning, but the industry has moved away from its original goal of offering free courses. Nowadays, the MOOC industry is driven by business models, and students usually don't receive a certificate for completing a MOOC for free. However, by paying a fee (typically a small one), students can obtain a paid certificate after

completing the MOOC. It's important for students to thoroughly read the information about certificates and associated costs before enrolling in a MOOC.

A major difference between traditional learning and MOOCs is the lack of exams and assignments. Most MOOCs do not require students to take exams, but instead provide a variety of learning activities to build their skills and knowledge. The course may suggest some small assignments to help students comprehend the material, but these are not mandatory. The purpose of these assignments is to help students develop their abilities and competencies and to deepen their understanding of the material covered.

Despite the variations from conventional education, MOOCs have become highly sought after. In today's society, education is deemed crucial but obtaining it beyond high school can be a daunting task, due to the hurdles posed by higher education institutions, such as entrance exams, tuition, distance, and living expenses. To address these challenges, universities globally have adopted MOOCs as a means to extend virtual access to students. Renowned institutions like Harvard are offering MOOCs covering subjects ranging from education to bioengineering. Furthermore, companies like Apple are offering educators free course creation tools via iTunesU.

3.1 Why MOOCs Are Not Game Changers for Education Yet

There are numerous MOOCs offered globally [24], including some from well-respected universities like Harvard and Stanford. These online courses provide an option for learners who don't have the means to participate in traditional, in-person classes and are considered a major innovation in online education. Despite the buzz surrounding MOOCs, their impact on education thus far has been limited and it's unlikely that universities will be shut down as a result, although MOOCs have the potential to greatly transform education in the future.

Despite the abundance of free Massive Open Online Courses (MOOCs) from various universities, a significant percentage of students who enroll in these courses fail to finish them. The dropout rate is estimated to be as high as 95%. One of the main reasons cited for this is the absence of interaction with a live instructor, as MOOCs are based solely on pre-recorded, self-paced video lectures. This lack of personal engagement can lead to a lack of motivation, guidance, and accountability for the student, resulting in a low completion rate of only 10%. Despite the abundance of information and resources provided by MOOCs, their format does not encourage interaction and collaboration between students, nor does it offer the same level of support as traditional education. The success of a MOOC is solely dependent on the learner's ability to remain motivated and achieve their objectives.

The present form of MOOCs, without live and interactive teacher interaction, is much like reading a book online. Nevertheless, there is a huge potential for MOOCs to revolutionize education if they integrate live teacher involvement. Some online learning platforms, such as WizIQ, are providing MOOCs with real teacher interaction, presenting a novel solution in the field of online education. With live instructor engagement, MOOCs can have a considerable impact on higher education. Economics also play a part, with the escalating cost of tuition and student debt favoring MOOCs. A study by Deloitte [25] found that tuition costs have gone up by 72% and earnings for 25-30 year olds have decreased by 15% since 2000, making MOOCs a budget-friendly choice for students.

Some universities have formed alliances with companies to create courses and career paths that meet the students' present and future needs, which can also help them secure employment after graduation.

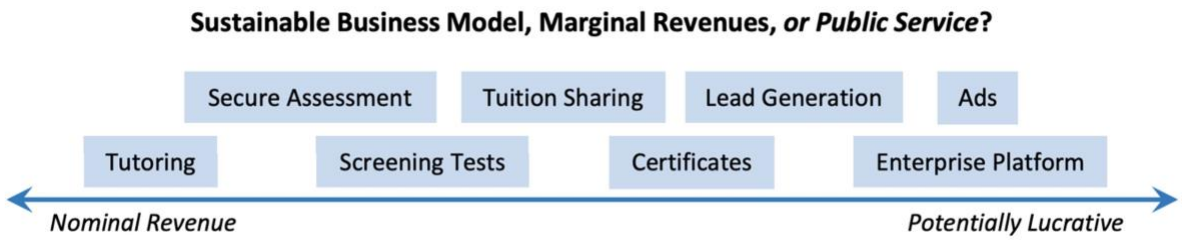

Figure 3.2: What will the disruptive element of the future for MOOC be?

If MOOCs can establish partnerships with companies and offer better job opportunities, there would be a compelling reason for people to choose MOOCs over traditional universities. However, this shift is unlikely to occur soon due to the strong social expectation to attend college and earn a degree, leading to the ongoing issue of student debt around the world. When this expectation decreases and economic factors become more crucial in determining education paths, MOOCs could potentially transform higher education.

Not only can MOOCs be useful in formal education, but they can also bring value to those who take courses for personal enrichment. For example, courses in arts, languages, cooking, etc. would greatly benefit from the presence of a live instructor who can give feedback on student assignments and ensure they are being done correctly. Platforms like WizIQ offer programming courses that provide access to virtual labs with live instructors to practice real-world scenarios, which is much more efficient than relying on video-based courses or trying to learn from YouTube.

In the near future, MOOCs are expected to shift from lacking instructor engagement to having much more of it. Currently, MOOCs operate in a model where students are taught by computers, which is not sustainable in the long run without live student-teacher interaction. Teachers play a crucial role in unlocking learning in MOOCs, helping students to overcome challenges and problems.

MOOCs are seen by many as a cure for the ills of higher education [26], with predictions of reduced costs, increased access, and the downfall of subpar colleges. However, these predictions hinge on unanswered questions: Will prestigious universities offer MOOC credits or full degrees? Will traditional college students consider virtual courses a substitute for on-campus experiences? Will working adults view MOOCs as an alternative to professional development courses? Will employers acknowledge MOOC certificates as proof of skills? Until now, MOOCs have not decreased the cost of operating a university, and only the wealthiest institutions have been able to employ them. However, once a high-quality virtual learning platform is built, the cost of adding more students is close to zero.

However, MOOCs are not only about revenue. With the huge number of students enrolling in them, many believe that there is a way to monetize such highly sought-after courses. Start-ups like Udacity and Coursera have proposed several potential sources of revenue that would keep the cost of education low or free for the majority of students. Meanwhile, the elite universities supporting MOOCs appear to be more focused on fulfilling their mission to increase access to education, generating positive publicity for their universities, and providing a

platform for faculty to experiment with new technologies. They see MOOCs as a way to increase their reputation, not as a threat, as shown in Figure 3.2.

The New York Times declared 2012 to be the “Year of the MOOC” [27], based on the promise that the world could now access a wide range of courses from the best universities [28]. However, by 2013, a

Washington Post article headline was “Are MOOCs Already Over?” [29], as one of the main problems that still plagues MOOCs to this day is represented by low completion rates. A study by the Graduate School of Education at UPenn found that only 5% of those who registered for a Coursera course actually completed it, based on a million participants [30].

A substantial number of MOOC enrollees do not actively engage in the course material. In the case of the UPenn courses offered on Coursera [30], only half of the registered students viewed even one lecture. This could be due to students registering for multiple courses and then choosing which to attend, or because of the demanding nature of MOOCs, modeled after traditional semester-long university courses. These classes typically require a time commitment of 12 hours a week, which may be too much for some MOOC students. The workload varies greatly between courses, with some requiring less than 40 minutes of video watching per week and others having over 7 videos and 8 assignments. The courses that have higher weekly time commitments and more homework assignments tend to have higher dropout rates [30].

3.2 MOOCs vs. Online Courses vs. Traditional Teaching

The “Report on Online Program Management Market for the Global Outlook and Forecast 2020-2025” [31] notes that graduate students are increasingly choosing to pursue virtual courses for their advanced studies, particularly in the case of MBA programs, which have seen a yearly growth in online offerings. This growth is attributed to several factors such as the increasing influence of eLearning concepts, advancements in Internet infrastructure, the need for skill enhancement, and the availability of affordable online courses [32].

Before the pandemic, the online program management market had already seen significant growth due to institutions and universities adopting various online programs. The COVID-19 pandemic further accelerated this trend. In the partnership model, the cost of launching a new course is *shared between the institution and the service provider*, reducing the investment cost while also improving the institution’s technological expertise in planning, designing, and launching online programs. This model generates high revenue for companies and enhances the learning experience, leading to the rise of virtual courses and programs and prompting top MOOC companies to adopt a partnership revenue model, which is expected to drive the growth of this segment.

What sets online degrees (TOCs - traditional online courses) apart from MOOCs? Table 3.1 presents some of the variations between the two. Both offer academic qualifications through the Internet, without the need for physical attendance. However, the key differences between them are: 1) delivery method and adaptability, 2) application procedures, and 3) cost.

When it comes to delivery and flexibility, MOOC-based degrees are made available through platforms such as EdX, FutureLearn, and Coursera. Many universities partner with these well-established platforms to offer their degrees, utilizing their technology to provide video lectures and evaluations for students to gauge their comprehension of the course content.

The manner in which online degrees are delivered varies between universities, but they typically include video lectures, live online versions of in-person classes, discussion sessions, and more. On the other hand, MOOC-based degrees are typically more flexible, allowing students to progress through the material at their own speed. However, students in online degrees from universities may have access to resources

MOOC: Content	Traditional Online Course: Content
- Content is accessible 24/7 - Media is open source - Learners are encouraged to share and contribute materials - Modules are 5 to 10 minutes - Content is edited when needed	- Often materials are only available one week at a time - Media is restricted by the university - Students search within an institution's library database - Modules are 45 to 60 minutes - Content is edited by semester
MOOC: Delivery	Traditional Online Course: Delivery
- Lectures are pre-recorded - All content is available from the start - Self-paced / customized learning path - Feedback is dependent on classmates - Course is open-ended with no due dates	- Often includes live lectures - Content is often locked until it is completed by the student - Group learns at the same pace / linear learning path - Feedback is dependent on the teacher - Course is closed ended with due dates

Table 3.1: Differences between MOOC and TOC.

such as office hours with instructors and campus libraries, which are not typically offered in MOOCbased degrees. MOOCs can be taken as a series of courses that lead to a full degree, and students can receive certifications for completing individual courses even if they do not finish the full program. In contrast, students in online degrees must complete all courses and other requirements, such as exams or internships, in order to receive their qualification. The application process for MOOC-based degrees is often simpler compared to online degrees, which may require students to submit a full application and take exams for graduate-level courses [32].

According to Dhawal Shah, founder of MOOC discovery platform Class Central, MOOC-based degree programs have a more open and flexible application process [32]. These programs are designed to reach a larger audience and admit students who demonstrate potential for success, as opposed to limiting admission like traditional online degrees offered by universities. For example, the University of Colorado at Boulder offers a master's degree in electrical engineering through MOOCs, using a unique approach called "Inverted Admissions", where applicants must complete some courses before being admitted, which Shah calls "potentially disruptive" [32].

In terms of cost, students enrolled in traditional online degrees pay the same fees as on-campus students, including out-of-state fees for international students [32]. However, MOOC-based degrees are typically less expensive. For instance, international students at Georgia Tech pay $40,000 per year for the oncampus Master's in Computer Science program, while the MOOC-based degree only costs $7,000 per year. The University of Illinois recently switched from offering an on-campus MBA to a MOOC-based iMBA in partnership with Coursera, which is priced at $22,000, much lower than the average cost of $60,000 for an MBA in the US [32].

Returning to Table 1, we notice several further variations [33]. In an online degree, educators have a more substantial interaction with students, leading to grades that better reflect the latter's actual performance. In most free MOOCs, grades are determined by either machine-graded assessments or evaluations from other students. Feedback from classmates can be useful if they provide thoughtful opinions, but it may also be hard to interpret and understand. Conversely, in structured online degree programs, assignments are generally graded by knowledgeable professors who provide tailored feedback and suggestions for improvement.

Group work is also a component of online degree programs, which prepares students for teamwork in the corporate world. On the other hand, MOOCs often do not involve group work and instead offer essays or quizzes as assignments. Finally, it's important to note that an online degree often requires a greater investment of time and effort, and may not be recognized as readily by employers as degrees from top educational institutions. MOOCs may provide certificates of completion, but it may take a while for them to be viewed as seriously as degrees.

With an online degree, students are given the chance for increased interaction with their classmates. In a smaller group setting, sharing experiences and building personal connections is easier. When there are hundreds of students in an online degree program, they have the opportunity to get to know their colleagues on a personal level as they work through various modules together and learn about each other's industries. This continuous interaction gives students a deeper understanding of their colleagues' jobs and provides a unique aspect to their learning. Moreover, online courses give the opportunity of global multi-cultural exchanges that can enhance the experience of students.

In summary, an online degree provides challenging assignments graded by experienced educators and may require group work. In comparison to MOOCs, it offers a more personalized learning experience, a more highly regarded credential, and better opportunities to form personal relationships.

Despite the advancements made by online degree programs, Massive Open Online Courses should not be disregarded. As Class Central's founder and CEO Dhawal Shah stated, the year 2020 saw a significant boost in the popularity of MOOCs due to the COVID-19 pandemic. By the end of 2020, over 950 universities had launched over 16,000 MOOCs, 1180 microcredentials, and 67 MOOC-based degrees, a vast improvement compared to 2012 [34, 35].

However, the MOOC experience has evolved over the years. Although the MOOC content has improved, the overall course experience has not. In 2012, everything in MOOCs was free, including certificates, videos, and assignments. Early MOOCs were adapted from on-campus courses, making them more rigorous and longer, with weekly or bi-weekly deadlines and limited attempts on assignments. The MOOCs of that time were massive, with one of the first MOOCs attracting over 160,000 learners, fostering a sense of community through the forums and helping students finish courses with significant effort.

The pandemic saw a surge in online learners, but the forum activity did not reach the level seen in 2012 [36]. As MOOCs grew, they had to remove professors from the active role of running their courses, leading to a change in the course structure, such as shorter courses with soft deadlines. The biggest change in recent times has been the increased availability of MOOCs, with a rising number of courses that users can start immediately. In the past, users often encountered finished courses, but MOOCs now have a more predictable schedule.

This also resulted in MOOCs evolving from virtual classrooms to a more self-paced experience, following a regular schedule with new sessions starting automatically on a bi-weekly or monthly basis. If a student cannot finish a session, their progress is transferred to the next session. This change has resulted in a significant increase in the number of courses that students can register for and start almost immediately [36]. When courses were only offered once or twice a year, students were all enrolled in one large session. However, now the same courses are available to be started anytime, allowing students to learn at their own pace in smaller groups. However, this shift towards increased availability has also resulted in a drastic reduction in forum activity within MOOCs. The move towards more availability was largely driven by MOOC business models, as more courses available at any given time means more opportunities for people to pay for certificates [36].

Over the last five years, MOOCs have retained their core principles, but the way they are packaged and sold has changed [36]. Initially, MOOCs were entirely free, including content, assignments, and certificates. However, as MOOC providers began to focus on monetization, some elements became

New Registered Users	2019	2020	Total
coursera	8M	31M	76M
edX	5M	10M	35M
Future Learn	1.3M	5M	15M
class central	350k	800k	2.3M

Figure 3.3: New registered users on MOOC platforms [37].

restricted to paid access. In 2013, Coursera introduced Signature Tracks, which allowed students to verify their identity and connect it to their certificate for a fee. Eventually, free certificates were discontinued and assignments were placed behind a paywall.

Nowadays, certificates and graded assignments in many Coursera courses can only be obtained for a fee. Both edX and Coursera have introduced paid courses, and all major MOOC providers have created their own credential systems, such as Coursera's specializations, Udacity's Nanodegrees, edX's xSeries, and FutureLearn's Programs.

Although a balance between course availability and social interaction would be ideal, it appears that paying students prioritize access over forum engagement. As a result, MOOCs with over 100,000 students are unlikely to reoccur. Despite these changes, students have generally had a positive response to the new MOOC offerings [36].

3.3 Learning from the MOOC Business Models

Despite the appeal of online courseware to universities that resembles the traditional learning model, there is also an opportunity to take lessons from the financial success of MOOC platforms. These platforms have made substantial profits from students who were once the main clientele of academia. In 2020, one-third of all learners who have ever registered on a MOOC platform did so, making it the most impactful year for MOOCs since the "Year of the MOOC", according to Dhawal Shah of Class Central [37] (his is also reflected in Figure 3.3).

In 2020, the top MOOC providers experienced growth and one of them (namely Coursera) emerged as the clear leader. The MOOC business reached 180 million learners in 2020 (as shown in Figure 3.4) and providers offered over 2800 courses, 360 micro credentials, and 19 online degrees, according to data from Class Central [37].

In 2020, the COVID-19 pandemic posed a challenge to traditional academic institutions. With universities transitioning to remote learning, many students had extra time and sought out online courses, with a preference for those that were free. MOOCs saw a surge in popularity as media outlets listed them as things to do during lockdown. Providers such as Coursera, edX, and FutureLearn experienced a huge influx of new users in April 2020, surpassing their total number of new users from the previous year,

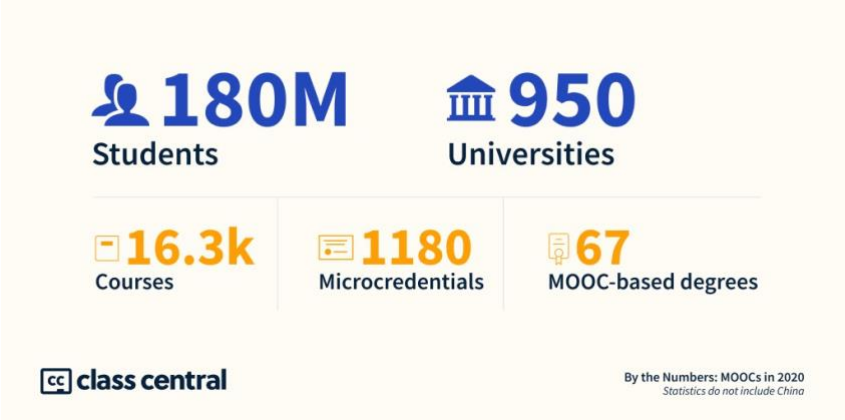

Figure 3.4: MOOC figures in 2020 [37].

	2012	2020
Funding	~100 million USD	~900 million USD
Learners	2 million	180 million
University Partners	40	950
Courses	250	16.3K
Revenue	0	Hundreds of millions

Table 3.2: The Second Year of MOOC in numbers for Coursera [37].

as can be observed in Figure 3.3. In response to the increased demand, major MOOC providers offered free courses related to COVID-19, free certificate courses, and free access to their course catalogs for university students. This allowed MOOCs to reach a wider audience with diverse interests during the pandemic, which is also exhibited in Table 3.2.

Nine years after the so-called “Year of the MOOC” [38], MOOC providers are collectively earning hundreds of millions of dollars each year [39, 40, 41]. In 2021, online education company Coursera went public and, according to a Bloomberg analysis [42], its revenue increased by 59% to $293.5 million in 2020, with losses of $66.8 million, up from $46.7 million in 2019, as can be seen in Figure 3.5. However, since 2017, Coursera has paid $281 million to its 200 university and industry partners, which is less than they earned in 2020. In 2020, Coursera had 12,000 degree students enrolled across over 25 degrees, with their consumer segment accounting for 65% of their revenue, compared to 90% in 2017. The MOOC platform business model is based on attracting customers, as the platform itself creates no educational content but instead pays partners for the actual work. This business model is similar to that of other online platforms that make millions without owning assets, such as Uber and Airbnb.

The validity of Coursera’s business approach has been subject to scrutiny. In [43], Shah compared Coursera and Udemy’s offerings, with Udemy boasting a massive library of 157,000+ courses. While Udemy was established earlier, in 2010, Coursera started out stronger due to its founding by Stanford professors and the boost it received from the 2012 MOOC hype. This gave Coursera more funding, users, and recognition compared to Udemy. Nonetheless, over time, Udemy has managed to close the gap and even surpassed Coursera in some aspects, as indicated in Table 3.3.

Udemy and Coursera do not develop their own courses, instead serving as online education marketplaces.

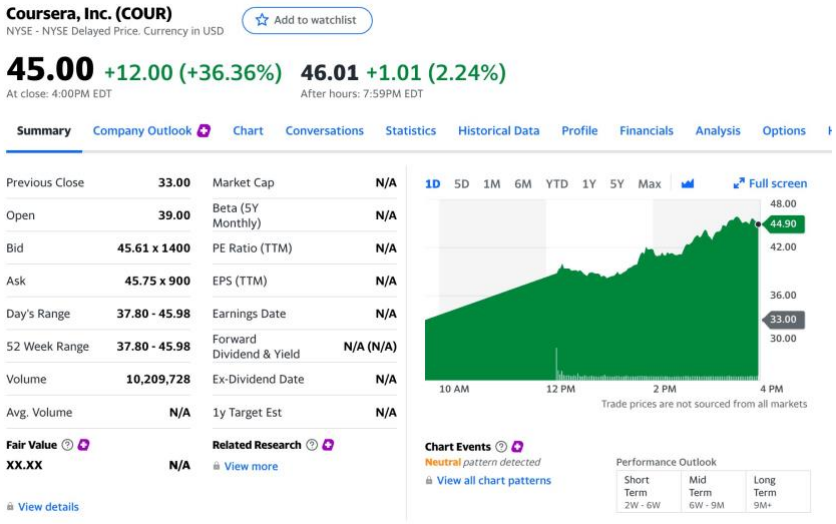

Figure 3.5: Coursera in numbers in 2021, after going public [41].

	Coursera	Udemy
Users	76 million	40 million
2020 Revenue	>>200 million USD	300 million USD
Valuation	2.5 billion USD	3.25 billion USD
Courses	6,500	157,000
Enrolments	>170 million	>425 million
Enterprise Customers	>2,300	>7,000

Table 3.3: Coursera vs. Udemy in numbers in 2021 [43].

However, their methods of who can create courses on their platforms differ. Udemy operates as an open marketplace, permitting anyone to create a course. As a result, Udemy has the largest collection of online courses globally, consisting of 157,000 courses created by more than 57,000 instructors, as seen in Figure 3.6. Despite this, many of these courses have low student enrollments, with a median of only 188, similar to Coursera. Business and technology courses make up half of Udemy's offerings and generate 70% of the platform's total student enrollment [43].

Conversely, Coursera operates as a curated marketplace, only allowing specific universities like Stanford, Imperial, and Uniandes, and selected companies and organizations such as Google, IBM, and The Linux Foundation, to create courses. The platform currently lists 230 partners and has a significantly smaller number of courses with higher average and median enrollment numbers, averaging 26,000 and having a

Figure 3.6: Udemy by the numbers [43].

median of 6,500 [43].

The bulk of the courses on Coursera are created through partnerships with over 100 universities globally. However, Coursera has been selective in its partnerships, only partnering with well-regarded universities, leading to its courses having a more academic focus compared to Udemy's more vocational course offerings. To broaden its offerings, Coursera recently launched Guided Projects under the Coursera Project Network. To speed up course creation, Coursera has opened up applications for subject matter experts through teach.coursera.org. Another benefit of Coursera's model and university partnerships is the ability to provide a variety of credentials, from single courses to complete degrees. Some of these credentials may have more value in the job market compared to Udemy's individual certificates [43].

Udemy's approach to revenue is relatively straightforward: each course is sold separately and once a learner purchases it, they have lifetime access. The only exception is the Udemy Pro subscription that provides 24 handpicked courses for IT certification preparation. For their business-to-business offering, Udemy for Business offers access to a catalog of over 7,000 courses, which is a smaller selection of their entire catalog. Udemy reports to have over 7,000 enterprise customers and as of October 2020, they announced that their enterprise business had produced $100 million in annual recurring revenue. Forbes estimated that Udemy's total revenue in 2020 was over $400 million [44]. In comparison, Coursera's revenue model is a bit more complex, since courses can be taken for free, but students must upgrade to gain access to graded assignments and earn a certificate.

As per The New York Times [45], Coursera was anticipating a 30% growth in revenue to reach over $200 million in 2020, but due to the pandemic, they surpassed this goal and reported a cash balance of $400 million, of which only a small portion goes to universities [46]. We believe that universities offering online learning should look to MOOC business models as a source of inspiration and consider collaborating with each other. The pandemic has altered the educational landscape and while universities remain a source of high-quality education, MOOCs are drawing in more learners, presenting an opportunity to supplement traditional funding.

The online education market is predicted to see growth in the future due to several driving factors including a rising popularity of eLearning ideas, developments in Internet technology, increased demand for skill improvement, and availability of cost-effective online courses. Institutions and universities are increasingly turning to online programs, leading to a substantial increase in the online education market. The partnership model involves sharing the cost of launching new courses between the institution and service provider, which reduces investment costs and boosts technological expertise in launching online programs. This revenue-generating model benefits companies and improves the learning experience. As a result, the rise in virtual courses and programs is motivating top eLearning companies to adopt partnership revenue models, which are expected to drive growth in the market in the future. Students are more likely to choose virtual courses for further education, with online MBA programs becoming more popular.

The certificate courses are an important segment for eLearning providers as many students seek to enhance their skills and knowledge through courses that align with industry standards. Online bachelor's degrees are becoming more popular among students as prestigious institutions shift towards offering highquality virtual degree programs.

In summary, up until this point, we discussed two things. 1) While online learning does offer many opportunities in reaching a wider and broader audience, it is not simply about moving traditional lecture halls in an online

environment, streaming classes with no interaction over YouTube. Students need proper attention and interaction with their teachers, they cannot be left alone with materials to lecture in their own pace. Critical thinking is something that must be encouraged. 2) We need to learn and partner with technology providers as much as possible. Universities are less dynamic in facing times, and until they develop and introduce the technology to students it might be too late. Universities should be responsible with teaching, this is their focus, while the business and technology models to reach a newly formed population of students should be externalized to the experts. This means that online learning and MOOCs should probably intersect at some point, little by little. An online graduate degree has rigorous assignments graded by professors and might require a lot of student group work. Compared with MOOCs, it can offer a more individualized learning approach, a more respected credential, and greater opportunities to form personal relationships and widen your professional network. But the online learning cannot be only about simply taking the traditional materials and offering them through an online platform, because this would be like making students transcribe from books back in the ancient times. It is simply not viable anymore, since most students have seen the other side of the mirror when going online in the last two pandemic years. More importantly, we believe that research, which university prevails at, should be part of this transition.

4 Research-Based Learning

The student's view of the learning process is significant, especially when new teaching approaches or technologies are adopted. The quality of their learning experience is shaped by their perceived level of learning achievement, support satisfaction, technical proficiency, emotional and intellectual stimulation, ease with the process, and sense of community.

The students' overall online learning experience involves non-teaching factors such as convenience, learner traits and preparedness, and preconditions that can boost education quality, but do not directly impact it [47]. Convenience is a critical factor as students' satisfaction with online classes is often lower than with in-person classes. Research generally shows that face-to-face and online modes are equivalent in terms of learning achievement. For instance, a recent study of business students showed that those who took part in a flipped classroom approach online outperformed their in-person peers, but rated their instructors lower [48].

Student characteristics, such as their ability to self-regulate in an active learning model, comfort with technology, and age, among others, impact their readiness and receptiveness to virtual learning. Instructor training and faculty motivation can also enhance instruction, but these factors are not directly perceived by students. According to [49], it is crucial to differentiate between the quality factors that students directly perceive and the preconditions that can contribute to improved instruction.

According to [50], our views on online education can be significantly shaped by our own biases and values. Accrediting bodies focus on technical requirements, demonstrating effectiveness, and maintaining uniformity. Universities place importance on their reputation, academic rigor, student satisfaction, and operational efficiency. Faculty are concerned with covering course content, student involvement, their own job satisfaction, and workload. From the student's perspective, learning outcomes are important, but they also view online education based on their enjoyment of classes, the instructor's quality, and their comfort in the learning environment.

Van Wart et. al [47] argue that students don't solely make their decision to take online classes based on their perceptions of quality, which are formed by their idea of the potential of online learning in terms of both academic achievement and enjoyment, as well as their expectations of the classes they choose. Convenience and flexibility are additional major factors that motivate students to enroll in online classes [51], and even if they prefer in-person classes, they will still sign up for online classes if their experience meets their minimum standards.

The challenge in assessing students' views on the quality of online education is the understanding of cognitive (how instructors engage students) and social presence (the creation of a learning community). All tasks performed by the instructor (such as creating a course, delivering lectures, clarifying assignments, offering practice, administering tests, grading, etc.) become more crucial in an online environment [47]. While lectures are a central aspect of in-person courses, their prominence decreases in online classes as recorded and live lectures and 24/7 become more prevalent. Taking a holistic approach to the pedagogical and technological

aspects of teaching is not very insightful. In this context, we next present the various factors that can influence a shift in students' perceptions from in-person to eLearning, as defined by Van Wart et al. [47].

- Instructional support represents students' views on the instructor's methods for delivering course material, providing practice, giving feedback, and evaluating performance. This encompasses clear instructions, use of multimedia resources, and a balance between repetition and diversity to keep students engaged. One example of a difference between face-to-face and online education is the popularity of the "flipped classroom" approach [52], where students engage in more hands-on activities and receive less lecture-based instructions.
- Teaching presence pertains to students' perceptions of the quality of communication in lectures, instructions, and feedback from the instructor [53]. It mainly encompasses the instructor's in-class performance. For instance, a well-designed course may still fall short if the instructor is not fully engaged, or an inadequately designed course may still be successful due to the instructor's strong communication and improvisational teaching skills.
- Basic online modality represents the proficient use of basic online tools [54], such as assignments, grading, forums, quizzes, etc.
- Social presence, as mentioned above, represents the students' impressions regarding the quality of peer interaction, for example in chat rooms or forums [55].
- Online social comfort is closely related to social presence and pertains to the instructor's ability to create an environment where students feel free to interact and share diverse viewpoints, without any fear or reticence.
- Cognitive presence relates to the extent to which students feel engaged and challenged by the material and educator, leading them to think critically and seek to understand varying view points [56]. This includes the provision of instructional materials and a learning environment that fosters reflection and inclusiveness [57].

The factors presented above are considered paramount to the students choice of in-person vs. online learning, and it has been shown that, out of all of them, the most important tend to be the instructor's basic online modality and the students' cognitive presence and online social confort [47]. It is also interesting to see these factors in the context of the COVID-19 pandemic, when many universities across the world quickly moved from limited online instruction to nearly full online classes. It is also interesting to see whether demand for online classes will return to pre-pandemic levels. Van Wart et al. [47] indicate that the ability and willingness of educators and institutions to provide high-quality online education will be as important in determining demand as students' growing comfort with online learning. They believe that, if the rapid transition to online classes leads to poor instructional design, inconsistent teacher involvement, and inadequate implementation of social and cognitive aspects, students may prefer traditional in-person classes. However, if instructors and institutions put in the effort to improve the quality of online classes, students may show a greater interest in hybrid or fully online classes.

The results of a recent study [58] indicate that students in virtual learning environments tend to perform better than those who participate in face-to-face courses. However, it was found that the success was not due to the

technology itself but rather how it was employed, since it can sometimes even hinder learning when not utilized appropriately. Educators who simply transfer their traditional classroom lessons to an online format often encounter difficulties and do not see any improvement in student performance. Effective online teaching requires expertise and a clear understanding of how to effectively integrate technology into the teaching methods. In [58], the author proposes seven evidence-based techniques that can have a significant impact on improving the online learning experience, for both students and teachers, which are briefly presented below.

- the virtual classroom plays a crucial role in the learning process, and it is essential for teachers to maintain its organization [59]
- it is essential for teachers to break down their lessons into smaller, manageable parts, since students' working memory capacity is limited, and thus they can only handle a few concepts at a time [60]
- it is important for teachers to not just focus on the students' understanding of the material, but also on their ability to access the virtual resources, so they should seek a significant amount of feedback [59]
- teachers should use annotations and interjections to support learning, and also incorporate questions at key points of the teaching process to assess understanding [61, 62]
- short quizzes and practice tests are an easy and effective way to improve learning outcomes
- teachers should counteract the negative effects of remote learning by building connections with their students, through regular and informal communication with students [63]
- teachers need to prioritize their own well-being [64].

We believe that it is important for universities to integrate these simple steps into their online learning approach, as part of a revised online class management strategy. The key to promoting research in universities rests with the students, who, with proper guidance, can generate original knowledge, highquality reflection, and educational value [65]. Instructional programs can actually serve as a catalyst for research by fostering critical thinking and examination of ideas that come up in the classroom and are adopted by the students.

In this context, Research-Based Learning (RBL) comes as a potential tool for integrating these steps [65]. It is an educational method that blends traditional classroom education with research methods. This approach encourages students to develop analytical, reflective, and argumentation skills while also enhancing their understanding of the course material. It involves students actively collecting and analyzing information, which allows them to play a more active role in their own education. This technique promotes critical thinking and encourages students to explore their own ideas, challenge their own opinions, and apply theoretical concepts to real-world problems. By becoming more involved in their own learning process, students develop a sense of ownership and responsibility for their education, leading to a deeper understanding and appreciation for the subject matter. Studies have shown that this type of hands-on, participatory approach to learning leads to more meaningful and impactful educational experiences.

Research-Based Learning is an innovative teaching approach that combines elements of research and education. Its key focus is to help students develop their own research processes and to inspire a high level of interest in being educated. This is achieved by giving students the freedom to explore topics and questions that interest them and to develop their own perspectives and questions.

In an RBL classroom, students can be given the opportunity to participate in the research process, from conducting research and reading related texts to writing and presenting their findings. The teacher acts as a guide, offering feedback and support along the way. This process encourages students to take ownership of their learning, making the knowledge their own by incorporating their unique experiences and perspectives. RBL also helps students to develop important skills such as critical thinking, problemsolving, and communication. By actively seeking and using a variety of resources and materials, students learn how to process and evaluate information and ideas, form interpretations, and think creatively and critically. These skills are then honed through writing and discussion, as students learn to communicate their ideas effectively [65].

According to Seif [66], there are five stages of Research-Based Learning, meant to encourage students to take an active role in their learning journey. The stages are: a) identifying relevant questions and problems, helping them understand the significance of their work; b) finding and analyzing information, thus learning to organize, categorize, and conceptualize information; c) thinking critically and creatively, by using the gathered data to interpret, analyze, and think creatively; d) applying knowledge and making conclusions or answering important questions; e) communicating findings through various methods such as research reports or slideshows.

In Research-Based Learning, educators play a crucial part in student achievement by promoting active participation in data collection and processing. The focus is on teaching students to find and process data independently, rather than solely relying on teacher lectures or manuals as a source. Teachers create a learning environment that stimulates curiosity, and they encourage students to think critically and solve problems. The ultimate goal is to empower students to take ownership of their education and to find meaning in it [66]. In this type of learning environment, the educator acts as a mentor, aiding students in formulating questions and problems, assisting in the identification and evaluation of data, and providing opportunities for students to draw their own conclusions and exhibit their findings.

The sustained use of RBL allows students to gain the ability to locate and utilize trustworthy information and resources, which is a critical skill for ongoing education. By categorizing, organizing, and synthesizing information, their thinking skills are enhanced. Engaging in long-term projects strengthens traits such as determination and adaptability. Moreover, students feel a stronger sense of ownership in their learning and have increased confidence in their education. What they learn becomes more memorable, since it is organized in a more captivating way. By incorporating RBL into their regular teaching, teachers are likely to observe higher student engagement and enthusiasm [66].

According to Chin and Osborne [67], the significance of students' questions in the educational process and scientific discovery cannot be overstated, since they have the potential to enhance both teaching and learning in science. Through RBL, students are equipped with essential competencies, including a thorough understanding of basic concepts, the ability to solve problems, and a scientific mindset. Moreover, RBL emphasizes the development of communication skills, technical proficiency, analytical abilities, and the capacity for collaboration. In essence, RBL is a learning approach that integrates research into the educational experience.

Susiani et al. argue that critical thinking is a key component of the necessary skills for future teachers, and that Research-Based Learning offers a unique learning model that helps develop it [68]. To improve students' critical thinking abilities, teachers must use teaching methods that encourage active engagement and real-world problem-solving.

5 Digital and Virtual Labs

5.1 Digital Labs

One important tool introduced recently is the digital lab. A proper Research-Based Learning process should start with the actual research, or with the data being input or resulting from it. Students should be asked questions such as: *How would you answer a research question like X if provided with the right data?*, and they should be provided with the data and scientific conditions to run their own experiments. This can be done with the help of Digital Labs, which are interactive tools (often accessible through an online platform) which allow students to recreate experiments in various areas. This includes collecting the data, processing and analysing them, and drawing conclusions about the results, all done through advanced simulations.

Technically, a digital lab refers to the use of digital technology in laboratory operations and the digitization of data processing to improve quality control, streamline workflows, and increase process efficiency. In the past, scientists relied on paper notebooks to record experimental data, observations, and results. This method was problematic as data from paper-based systems are not easily shareable, searchable, standardized, or accessible, making it difficult to maintain the integrity and value of an experiment.

The traditional use of paper in laboratory operations is being replaced by digital technologies, which streamline the procedures and improve quality control, making laboratories more efficient. This shift is driving the adoption of Open Science, which promotes the use of digital tools to enable reproducibility in scientific research. In a discussion on transforming research and development and data control with cloud-based informatics, Clark Leininger, Lab Workflow and Data Stewardship Client Partner at Pfizer, said: *"Data is at the heart of everything we do in science and in the lab. Digital labs can offer meaning to the data collected as it allows scientists to find more openness in and around the data. Scientists can make decisions efficiently based on the output from analytics, digitalized laboratory informatics systems and connected devices. These elements combined with the support of people will ensure research results are achieved much faster"* [69]. Here, we say students can be part of the process as well, to ensure learning outcomes are achieved must faster.

However, to fully realize the benefits of digitalization, universities must tackle the challenge of managing the vast amount of data produced by digital systems. This includes data with high velocity, variety, and volume, and universities must find effective solutions to effectively handle this data in order to successfully scale their digital transformation strategies in the laboratory.

Figure 5.1: Achieving the digital lab transformation [71].

Dr. Haydon Boehm, Head of Commercial Marketing - Connected Lab at Merck Group, stated that *"Up to 70 percent of research is currently not reproducible, often due to the inability to find the original research data, or because the experimental conditions are inconsistently or inadequately catalogued"* [70]. To navigate legacy applications and maximize data insights in the lab today, Dennis Della Corte, Chief Science Officer at ZONTAL, said that *"Making data findable, accessible, interoperable, and reusable (FAIR) will help [...] companies eradicate data silos with high maintenance costs, enhance data interoperability and integration, improve compliance and data integrity practices and drive new data driven solutions for continuous innovation and business transformation"* [71].

A key component linked to digital labs, open science has shown its ability to accelerate the critical research process during a globa emergenciy like the COVID-19 pandemic [72]. Scientific advancements have been made at an unprecedented pace during this crisis, with the full genome of COVID-19 being made available as an open-access publication just one month after the first reported case.

However, relevant for us is the fact that streamlined access to scientific data, full data transparency, and the removal of manual processes in the lab can enhance the speed of scientific research and hasten the launch of products to the market. Furthermore, the digital lab offers a new generation of specialists the chance to gain knowledge they might not otherwise have access to [71].

For scientific data to be utilized in education and made visible, universities must collaborate with technology providers and those who work in the labs. The most advanced IT systems are worthless if people do not embrace or use the technology. The digital lab's effectiveness is determined by efficient data management and the input of accurate information by those using the systems. We believe that the future of education also requires students to gather data and pose relevant questions. To ensure a successful migration to the digital lab of the future, universities should consider following certain recommendations [71]: a) utilize the principles of FAIR data in the R&D process; b) implement risk-based validation techniques; c) build a data-focused culture; d) enhance data with analysis algorithms to include lab intelligence. Uwemedimo [71]: proposes three stages on the road to achieving a digital lab, as shown in Figure 5.1.

Based on the ideas of RBL and digital lab, one can imagine that students could be presented with a similar data-driven approach to unleash their full potential into constructing a methodology for finding, for example, antibodies for a vaccine. This is what Research-Based Learning is about and this is its

Figure 5.2: Views of the 3D virtual lab environment at the University of Glasgow [73].

potential for forming critical thinking skills. Data need to stay in university repositories and be completely accessible to students and researchers eager to explore their potential.

5.2 Virtual Labs

A solution to the challenges faced by universities with limited laboratory facilities and a shortage of experienced instructors, virtual labs offer remote access to simulation-based experiments in various scientific and engineering disciplines, designed to stimulate students' curiosity and allow them to learn at their own pace. This student-centered approach enables students to grasp both basic and advanced concepts through simulation-based experimentation, enhanced by additional web resources, video lectures, animated demonstrations, and self-evaluation. In other words, virtual labs represent an implementation of the Research-Based Learning paradigm.

Virtual labs offer several benefits, including access to online laboratories for educational institutions without proper facilities, complementary access for universities with existing labs, and the opportunity to improve skills and training through workshops and online or on-site training. Furthermore, they offer the flexibility of learning anytime and anywhere, being a shift towards student-centered, online education. They help students learn basic laboratory techniques, gain exposure to good scientific lab practices, and prepare for careers as lab technicians and researchers.

As shown in [73], the COVID-19 pandemic has led to limited access to laboratory facilities for both teachers and students, as the lockdown caused many people to be unable to physically visit a lab for more than a year. Nevertheless, this situation has also presented an opportunity for advancements in science education, such as innovative virtual lab environments created by university educators using tools such as LearnSci [73], allowing for immersive experiences for students through virtual 3D labs. One example where LearnSci was used successfully was the Molecular Methods course at the University of Glasgow, which typically covers advanced molecular biology techniques used in the industry through a combination of lectures and lab sessions over five days. However, due to the pandemic, the course was redesigned to be delivered online through a 3D virtual lab environment and a virtual lab book. The course material was organized into chapters on Moodle, where students could participate in virtual experiments through worksheets, videos, quizzes, and lab simulation, preserving (as best possible given the circumstances) the hands-on experience of the in-person course. A virtual lab simulation app was integrated into the final day of the course, created in partnership with Sublime Digital, and modeled

Figure 5.3: The Hololens-based setup at the Queen Mary University London [73].

on a laboratory at the university and accessible through Zoom. Figure 5.2 shows two views of the 3D virtual lab environment.

An additional example of applying virtual labs was implemented at Queen Mary University London for a practical chemistry laboratory which needed to also be available to students that could not physically participate. The solutions was a mixed reality virtual lab that utilized Hololens headsets worn by the teachers, which transmitted a live feed of the experiment being performed to students connected remotely. Figure 5.3 shows two screenshots of the setup.

The concept of virtual labs is growing in popularity as organizations aim to broaden their reach, reduce expenses, improve student comprehension, and offer a unique form of hands-on training for aspiring scientists. As an example, edX launched its own lab simulations under a project called LabXchange.

Virtual labs come in different forms, from basic 2D video games that utilize simple controls to manipulate a limited number of variables, to more sophisticated 3D simulations designed to offer a more immersive experience. Some virtual labs provide students with specific objectives and step-by-step instructions to guide them through complex procedures, while others allow students to roam freely in the digital world. Proponents of virtual labs emphasize the benefits of technology in enhancing education, with virtual labs shown to improve certain test scores and prepare students for real-life scientific experiments [74]. However, there remains an ongoing debate as to whether virtual labs are more effective than traditional textbooks in promoting learning, whether their 3D graphics are helpful or simply a distraction, and whether simulations can truly replace actual laboratory experience.

Other solutions similar to LearnSci are Labster or LabSims, which aim to create a realistic laboratory experience for their users. Labster's simulations incorporate features like shadow and light, allowing users to navigate their virtual surroundings. For actions that would involve physical touch, users must mimic these actions with mouse clicks. Although virtual labs do not have the same financial resources as the video gaming industry, the simulations still offer a gamified perspective, with details such as characters who talk to you that enhance the immersive experience. Many virtual labs use storytelling to make them more captivating (especially ones oriented for a younger target audience), such as Labster's animal genetics lab, where players end up visiting a farm. The use of gamification has been shown to increase student motivation, but the impact on understanding depends on the design of each simulation.

Studies have shown that there is not much difference in the learning outcomes between students who carry out virtual lab experiments and those who carry out real ones, regardless of topic or age [75].

Despite not being able to physically touch anything in a virtual lab, this limitation has proven to have a minor impact.

One study focused on immersive virtual lab simulations was conducted by Mads Bonde [76], the cofounder and CEO of Labster, at the Technical University of Denmark. He and his team provided a group of first-year life science students with access to a Labster simulation of a crime scene investigation. The students who completed the simulation scored, on average, 76% higher when tested compared to those who received traditional teaching methods.

In the future, virtual labs may be utilized in universities to accommodate the varying learning paces of students and to overcome the limitations posed by real-world laboratory space. While virtual labs provide a cleaner and faster learning experience, free from the distractions of physically handling equipment, they also limit hands-on experience and the ability to handle and troubleshoot equipment. By shifting some laboratory studies into the virtual realm, scheduling conflicts can be avoided, and students can focus on understanding scientific principles [75].

It is hard to predict whether virtual labs will entirely substitute practical laboratory work in scientific education in the near future, but that does not necessarily mean they do not have value. The use of virtual labs should be considered as complementary, as they can can help enhance learning outcomes when used appropriately. For individuals without access to actual labs, a virtual lab experience is better than no laboratory experience at all.

6 Future Learning

The swift spread of the COVID-19 virus in spring of 2020 and the sudden halt of in-person teaching at universities globally has necessitated an abrupt shift to virtual remote teaching [77]. However, it is important that the efforts invested in adapting to online learning are utilized effectively, as the world will never revert to its pre-COVID state. The shifts in demographics, the speed of technological advancements, and the impact of globalization are putting significant pressure on higher education institutions to offer accessible and inclusive education. The sudden interruption of higher education that started in March 2020 has created opportunities to inspire innovation and drive major change [78].

When the pandemic caused universities to lock down, many education institutions were not equipped to deliver effective online education due to a lack of preparation and investment in digital systems. Despite the significant resources devoted to educational technology, higher education had not yet made the transition to delivering online education on a large scale. Although digital learning allows universities to reach a wider audience beyond the traditional classroom setting, the effectiveness of large-scale online education remains a topic of controversy, particularly with regards to MOOCs [79]. However, this skepticism has led to innovation and the development of more affordable large-scale online programs [80]. Furthermore, the same technology that made MOOCs popular is now being utilized by many universities to provide remote learning to their students [81]. In the following, we discuss some thoughts on what teaching should be like post-pandemic.

We start with two examples where critical thinking is greatly tested in an online setting, and the first one is mathematics. Conventional wisdom suggests that teaching math requires the use of traditional methods such as writing on a chalkboard. Math is a subject that heavily relies on critical thinking, which means that students must find their own solutions to problems through active engagement. This is where Brainika!, a learning platform designed for children, comes in [82]. To foster a natural understanding of mathematics, the platform effectively teaches fundamental concepts through repetition, recall, intentional practice, feedback, and positive reinforcement. These methods are among the most effective ways to build mathematical intuition in the brain through a procedural process.

The second example is computer programming, where James Bowen, a Java and DevOps teacher and author in the field of computer programming, has taken the basic principles of procedural and declarative learning and applied them to enhancing coding skills [83]. He introduced the concept to developers and specifically applied it to the learning of Kotlin. Currently, James is focused on assisting coders in developing the ability to consciously identify opportunities while executing the skill automatically.

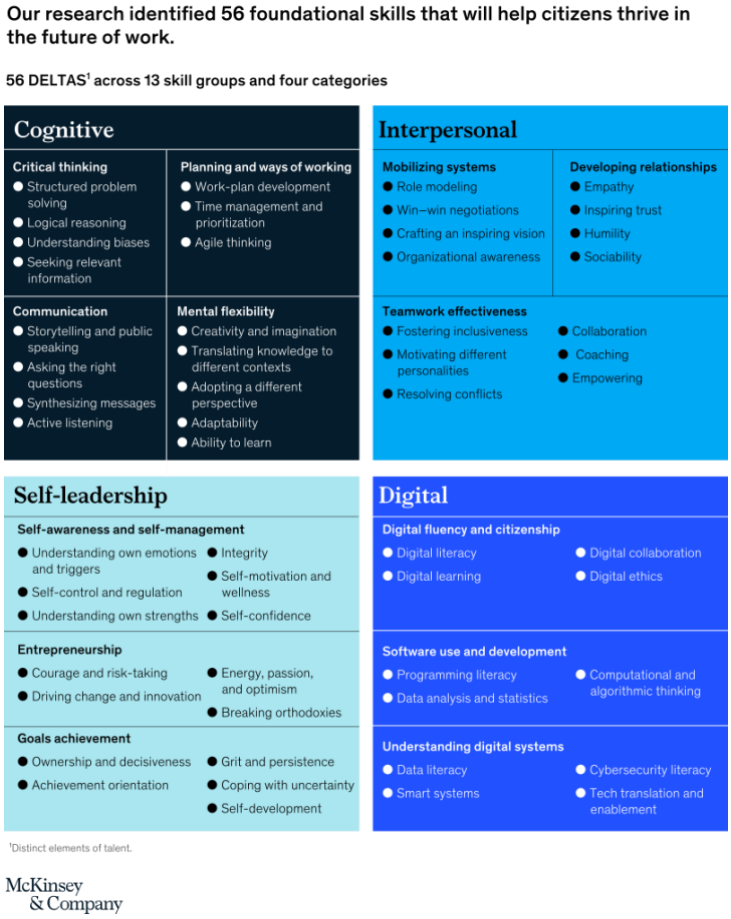

Figure 6.1: Skills required for the future of work [84].

The pace of change in the world is undeniable. Automation is taking over tasks once performed by humans, and the digital era is transforming our familiar world. The fourth industrial revolution is underway, and it's critical for people of all ages to grasp the skills required for future work, stay abreast of new technologies and complex systems. But before we can do that, we must first return to the basic skills that will make us successful in both current and future workplaces. McKinsey [84] has identified the set of skills necessary for the future of work, and active learning is the key to developing these skills (as depicted in Figure 6.1). The traditional education system can be adapted to benefit those seeking to prepare themselves for the future.

The 21st century and future of work require a diverse set of skills, and education plays a crucial role in imparting these skills. Figure 6.1 presents 56 future work skills categorized into four subgroups: cognitive, interpersonal, self-leadership, and digital. These subcategories cover the essential skills for the future of work. The cognitive skills, such as critical thinking, planning and ways of working, communication, and mental flexibility, are crucial to success in the changing world of work. Effective communication and critical thinking will be key to future careers. Interpersonal skills, including mobilizing systems, developing relationships, and teamwork effectiveness, are necessary in any future work environment. Strong interpersonal skills are crucial for working with a team to achieve results. Self-leadership skills, including self-awareness and self-management, entrepreneurship, and goals achievement, are critical for success in the future of work. Being a leader and being self-aware are top priorities. Digital skills, including digital fluency and citizenship, software use and development, and understanding digital systems, are increasingly important in the future of work. As a technology talent training program, digital skills are closely related to our goals. Being knowledgeable and ethical in all things digital is a

must for success in the future. Digital skills are essential as the digital world continues to grow and shape the future of work [84].

The significance of active learning as an educational resource has never been greater. From the outset, students should be motivated to work together with other students to cultivate the skills needed for the future workplace. As mentioned in the McKinsey article, *"Some work will, of course, be specialized. But in a labour market that is more automated, digital, and dynamic, all citizens will benefit from having a set of foundational skills that help them fulfil the following three criteria, no matter the sector in which they work or their occupation: add value beyond what can be done by automated systems and intelligent machines, operate in a digital environment, and continually adapt to new ways of working and new occupations"* [84]. Active learning provides students with a dynamic way of learning that gives them greater control and flexibility in their education. This approach allows students to experiment with different methods, learn from their mistakes, and understand concepts through practical application instead of just hearing about them. The effectiveness of simply taking notes during a lecture cannot compare to actively engaging with a concept and putting it into practice in real-world situations.

Education plays a crucial role in developing skills that are in high demand for the future of work. Some of the skills that are closely linked to education are Digital Literacy, Programming Literacy, Data Analysis and Statistics, Building Trust, Driving Change and Innovation, Positive Energy, Passion, and Optimism, Collaboration, and Digital Learning. By consistently practicing and reinforcing these skills, students can achieve better results and be better prepared for the demands of the 21st century.

Interpersonal skills can be developed through a combination of teamwork, systems, and relationship building. For instance, during stand-up meetings, students should have opportunities to interact with one another as well as program managers. They can discuss topics related to their weekends, share fun facts about their interests, give updates on their projects, ask questions about their challenges, and connect with others who are at similar stages in the program. Students should be able to work through problems and conflicts while collaborating with different people in a team. They should be empowered to take risks, answer tough questions, apply for their dream jobs, and impress interviewers.

To foster cognitive skills, students must take on the challenge of critical thinking, effective communication, and self-management. Online education programs, with their self-paced and remote nature, provide students with the flexibility to balance their learning with other important commitments in their lives. By allowing students to find a learning style that suits them best, they are able to engage in projects that demand creative thinking and prepare them for future employment and careers. Encouraging students to articulate their thought process and reasoning to others, through coding collaboration and public speaking, deepens their understanding and problem-solving abilities. Every project should involve structured problem solving to further enhance their cognitive skills.

For self-leadership development, students should be given opportunities to enhance their self-management, self-awareness, entrepreneurship, and goal-achievement skills. Each meeting should boost their selfconfidence and emotional energy, as well as their confidence. Students should be encouraged to take risks, submit exercises, and have ownership of their projects, driving their passion for programming. The self-development component of this process is evident at the end of their track when they receive job offers from top companies.

In terms of digital skills, education should be centered around digital learning, offering various tracks and programs to teach the necessary programming languages, platforms, and systems for the 21st century.

6.1. The Distributed Classroom

By focusing on these four skill areas, we aim to prepare students for the future of work. We must continually inspire and encourage students to grow both in their code and personally, each day.

Programs aimed at equipping adult learners with the skills they need for the future are increasingly becoming essential in light of the rapidly changing world. McKinsey's report highlights the critical nature of these skills and their relevance for the future [84]. However, traditional educational institutions, including universities, are not providing the level of education required for graduates to be equipped for today's job market. There is a significant gap between what these institutions offer and the skills demanded by employers. The current education system, including its curriculum and learning model, needs to be drastically reformed to effectively meet the needs of today's learners and prepare them for the future

Hands-on practice is the key to mastering the skills described above. Simply transmitting knowledge is not enough to equip students with what they need to know. Mental flexibility, for example, can only be developed by putting learners in situations that require them to be flexible and push their boundaries. A lecture format, where students are not actively engaged in the learning process, will not provide the emotional or mental stimulation required for developing these skills. Although students may feel they have learned more through lectures, research has shown that experiential learning is much more effective, even if students may initially resist it. Even if change can be difficult, the sooner students embrace new learning methods, the sooner they can develop the skills they need for the future of work

6.1 The Distributed Classroom

When we bring together various educational initiatives, a revolutionary concept emerges known as the distributed classroom. This refers to a classroom experience that transcends geographical and temporal barriers. The teacher and students don't have to be in the same place at the same time. The teacher can instruct students in the same room, remote students, or both synchronously or asynchronously [85]. Unlike traditional asynchronous online learning, where students watch pre-recorded lectures and communicate through online forums or chats, the distributed classroom is not restricted to one mode of learning. The teacher can teach a class of students in person, while also livestreaming the lecture to remote students who have access to their own teaching assistants for support and interaction. These assistants can facilitate communication between the teacher and remote students during the lecture. All students, both in-person and remote, can continue to engage with the teacher and the full teaching team through asynchronous means or synchronous remote sessions, such as dedicated online office hours.

The prepared lecture can also be recorded and used for fully asynchronous learning. For instance, for a course in Europe, students located in the United States may view the course material with a 10-hour delay due to time differences, or remote adult learners who log into an online platform such as Microsoft Teams can watch the content together after work. In these scenarios, instructional support will be provided to facilitate and structure their interactions and answer questions that can be answered by a typical teaching assistant. Although these synchronous interactions are optional, they enhance the learning experience and reintroduce social interaction that students otherwise had to sacrifice to participate in the program without moving to Europe or committing to classes during work hours. All students can interact with their classmates and instructors on shared course forums, submit their assignments, and receive grades and feedback through an LMS such as Moodle, from the same group of teaching assistants. This is what the distributed classroom aims to achieve: distributing not only learning across time and

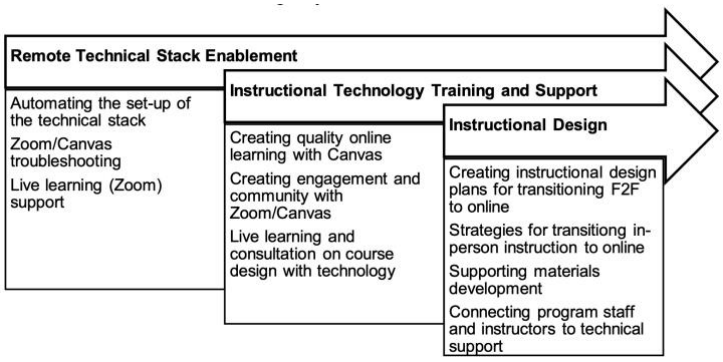

Figure 6.2: UC Davis CPE division plan [81].

space but also the actual classroom experience, including synchronous interaction, while eliminating the need to be present at a specific time and location [85].

An interesting example of a distributed classroom implementation is presented by Schwedler in [81], with a use case at UC Davis, a renowned public research university in the US. They addressed the COVID-19 pandemic through their Continuing & Professional Education (CPE) division. Prior to the outbreak, CPE's fully online courses made up 20% of its credit and non-credit offerings, while the organization's broad reach was largely achieved through its five-year partnership with Coursera [81], which allows CPE to reach over one million students, providing greater access for both national and international learners, and especially working professionals. However, CPE also had its own technological systems that allowed it to offer academic certificate programs in various fields, including business, health, and technology.

The CPE team operated in a traditional hierarchical manner and focused on building online courses and managing the learning management system. However, the Centre for Online Education (COE) at UC Davis was not providing widespread training or support for instructors and students. With the sudden shift to remote learning brought on by the pandemic, the COE quickly adapted and provided professional development to 400 instructors and staff, established just-in-time support solutions, and provided in-depth instructional design consultations [81]. Within two weeks, the COE team transformed its approach to online learning to meet the changing needs of students and instructors [81].

The CPE division thus successfully adapted to remote work and instructional delivery during the COVID19 pandemic. To avoid faltering during the ongoing pandemic, the organization had to continuously innovate. In response to the crisis, academic leaders absorbed instructional support to provide programmatic continuity and were closer to instructors and students. As the pandemic kept people at home, the CPE leadership centralized instructional support within the COE team, allowing academic staff to continue improving and developing new programs. Once program areas stabilized, UC Davis transferred the responsibility of organizational instructional support to the COE team, as shown in Figure 6.2.

Based on Schwedler's findings, Table 6.1 illustrates the alignment of instructional delivery with technology, which gives teachers access to various tools to design captivating educational experiences, with the assistance of technology and support specialists. By collaborating with the online instruction and support team, both instructors and learners can receive training and skills development to guarantee success in this form of delivery.

Delivery model	Required	Recommended
Synchronous	- Zoom basics training, either live learning or drop-in practice sessions - Accessibility, privacy, and security training with technology stack	Canvas basics and engagement training
Hybrid online	- All of the above - Canvas basics and engagement training to learn about the tools available for delivering asynchronous learning	Video-creation training
Fully online	- All of the above - Video creation training	Active learning strategies and tools

Table 6.1: Instructional delivery model alignment with technology [81].

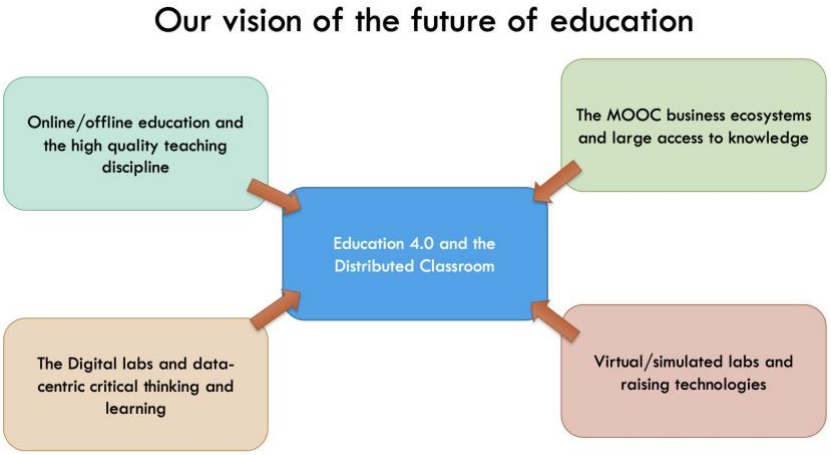

Figure 6.3: A proposed vision.

6.2 Education 4.0

In line with all these, we present the future of the education as envisioned by the Erasmus+ LLSF project in Figure 6.3.

In our vision, Education 4.0 is a mix between learning, where online lectures are complemented with self-paced online practice activities, and science, where students are co-designers and co-creators of new knowledge. Laboratories are main generators of both education and innovation capabilities. By transforming labs to become digitally enabled, globally connected powerhouses capable of breakthrough innovation at scale, we believe to be able to turn the tide of innovation and future education capabilities. The big challenge? Navigating oceans of information. An unprecedented number of experiments are being explored today in many science domains. Innovations, while incredibly exciting, have also exposed a fundamental weakness in laboratory operations: the collective inability to harness the power of the oceans of data we generate. The project proposes to adopt an end-to-end data strategy and then execute against it: connecting data from disparate sources like labs, collaborators, and the real world to generate insights. Or, in other words, connected data is key to transformation.

According to the Vision of the European Commission, the EU's digital decade evolves digitalization with a clear focus on data, technology, and infrastructure. To be a leader in this new data-driven world, universities must fundamentally transform how they create, manage, and effectively use all the data that is generated in labs across their ecosystem, from internal labs to the many partners with whom they collaborate, to expose truly data-driven "digitally transformed labs". Technologies (see Figure 6.4) such as extended reality, artificial intelligence/machine learning (AI/ML) and Internet of Things (IoT) are mature and affordable enough today to enable real transformation of the lab. Through the development of the international network of interconnected smart labs that we are proposing, we aim to provide students from Master and PhD levels from different parts

of Europe with flexible digital study options. The aim is to ensure a more accessible higher education by providing the right conditions for students

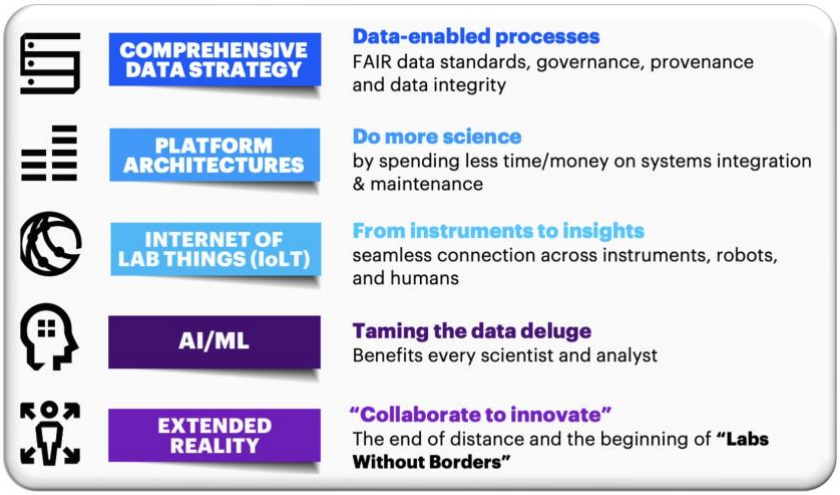

Figure 6.4: The future: extending the range of studies with Interconnected Labs.

of different backgrounds to succeed, but also by using a delivery technology that is accessible all around the world. The project will thus provide digital readiness (in terms of IoT studies) to the universities promoting the project, but also resilience of educational services in the face of unexpected events, like the COVID-19 pandemic. This aspect of the project will thus refine the user experience and content so that the online platform provided through the project can contribute to a better digital capacity for universities.

Our proposal combines aspects of all four previously discussed direction in online. At the core, it is about the adaptation of the learning methods (Education 4.0) and supporting infrastructure (Distributed Classroom) to make active use of Active Learning and Research-Based Learning over online distributed virtual labs. In the project, we will be using a multi-level strategy (Figure 6.4) that tackles the different aspects, from the infrastructure to data-provisioning to learning adaptation, needed to adapt teaching and universities to a post-pandemic online strategy.

In this project, five universities work together to create a training environment where students learn on their own pace through experimentation the use of digital technologies, by actively working with data and applications over smart remote laboratories.

Scientists are able to showcase their data and put at use readings from sensors capturing information in experiments and being able to analyze data remotely in digital labs. All this is part of a culture towards the use of technologies for the development of Smart Labs (as part of a Living Labs culture).

Our newly created Smart Laboratories (where the learning experience is centred around data) will support:

- online training for smart specialization on IoT and Big Data technologies
- innovation through common data procreation.

An example of a digital ecosystem fostering a living lab culture at UPB can be seen in Figure 6.5. Thus, we believe such a virtual infrastructure will allow for remote teaching of ICT disciplines, from
Big Data/Cloud concepts to Mobile Computing and Internet of Things. To give an example from the University Politehnica of Bucharest, in Romania, the PRECIS building is equipped with a smart building

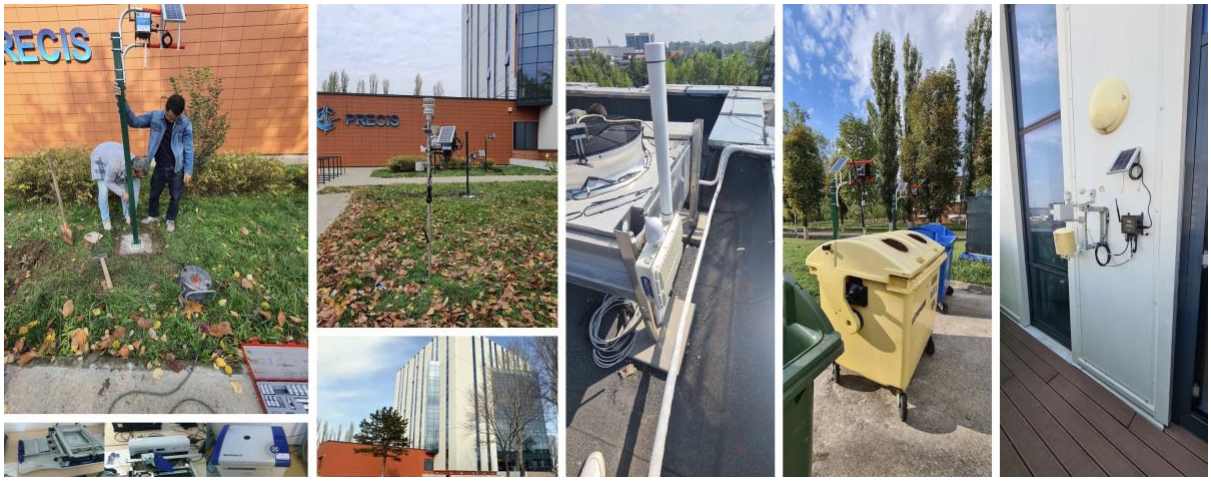

Figure 6.5: Living lab at UPB.

management unit which will be provided as a virtual infrastructure, as well as various sensors can be read and worked with remotely. Students form their competences over emulators of such a system, and with the right security clearances even interact with live environments. And scientists will be able to create their own experiments, for example to test their theories on energy influence in the building. And all these equipment, and data and tools, will be accessed for teaching activities by members in the project, according to the solutions we deliver within the LLSF project.

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