

Technological Change and Its Effect on Education**A Y Klimenko***

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Submitted: 2024, Feb 05; **Accepted:** 2024, Mar 11; **Published:** 2024, Apr 04

Citation: Klimenko, A. Y. (2024). Technological Change and Its Effect on Education. *J Edu Psyc Res*, 6(1), 01-18.

Abstract

This work follows the historical interplay between technological advancements and educational systems and highlights that strengthening education has been a key driving force behind the Second and Third Industrial Revolutions. It seems, however, that the arrival of the Fourth Industrial Revolution --- bringing communication platforms, AI and renewable energy --- caught educational institutions unprepared. Whether we like this or not, this technological shift means the educational landscape is bound to change. This article examines the evolving dynamics of modern education amidst a new wave of technological progress, highlighting the rise of student 'collectives' which result from a distinctive synergy among students, communication platforms, and generative AI technologies. The article expresses scepticism regarding the use of strategies that are becoming practically ineffective, technologically outdated and contradictory to prevalent student practices. It advocates for adopting educational principles appropriate for the modern era and capable of upholding academic integrity in the strictest sense. If modern technology seems incompatible with academic integrity when examined within some traditional educational practices, this can mean only one thing---these practices must change. A significant challenge lies in implementing these changes without overburdening already limited educational resources. The article proposes practical principles and measures to ensure that universities can still be a driving force behind technological progress and innovation while upholding and promoting the highest standards for their research and education.

Keywords: Technological Change, Energy Transition, Generative AIs in Education, Collective Class Psychology, Integrity in Education and Research

1. Introduction

Technological development and education have been interlinked since ancient times [1]. The first urban civilisation --- the Sumer --- was remarkably inventive and many of its inventions (bricks, wheels, writing, etc.) are still used even today. It does not come as a surprise that Sumerians introduced formal schooling of students in Cuneiform grammar and mathematics. While economic and political life in Rome was remarkably advanced and, in many respects, similar to the modern world, Romans were not particularly inventive, at least in comparison with their achievements in politics and law [2]. Roman civilisation is marked by impressive attainments in architecture but not by technological breakthroughs that are comparable to the scientific and technological achievements of ancient Greeks, medieval Chinese or modern Western civilisations. Roman education is very much consistent with this notion focusing on Greek literature, ethics and rhetoric while paying relatively little attention to mathematics, geometry and technology.

The existence of a common positive correlation between education (especially education linked to science and technology), accumulation of knowledge, inventiveness and technological progress is beyond doubt [3, 4]. The widespread

printing of books and the Scientific Revolution of the 16th and 17th centuries preceded the Industrial Revolution of the 18th and 19th centuries. Yet a more detailed consideration of recent technological surges reveals a more complex picture that is analysed in the present work. Technological developments in the modern age were not monotonic but characterised by surges or leaps that are often referred to as technological revolutions [5]. The analysis of the next section (Section 2) shows the increasing importance of technical education as the industrial world proceeded from the First to the Second and then to the Third Industrial Revolution [3]. Yet this tendency stalled (if not reversed) in the transformations that preceded the emerging Fourth Industrial Revolution [1]. This partial reversal of the previous trend is accompanied by another trend reversal. While the persistent educational effort of the last two centuries improved the knowledge and skill base in a way that underpinned accelerated technological progress, it is technological change that has begun to shape and transform educational practice [6-8]. These transformations might not be immediately apparent in class but are nevertheless profound and have been at the centre of ongoing debates and publications [9-10]. Section 3 is dedicated to analysing these changes, focusing on collective psychology and the emerging presence of AI in the classroom. Technological

change and classroom psychology have become interlinked and, therefore, need to be studied together. The challenges of adapting university education to new conditions are discussed in Section 4, which offers a set of recommendations that can, in the author's opinion, help achieve this goal. Section 5 offers some generalisations and conclusions. Appendices present some details on technological surges and the detection of texts generated by AI.

2. Technological revolutions and education

2.1. Five Technological Surges that Changed the World

The cyclic nature of techno-economic development during the times of the Industrial Revolutions has been established by a number of distinguished scholars: Nikolai Kondratiev, Joseph Schumpeter, Christopher Freeman and Carlota Perez [11-13]. The fundamental concept of creative destruction introduced by Schumpeter implies the destruction of the obsolete segments of the economy to give way to innovation and technological progress [11]. This all-encompassing change is expected to affect and be affected by education as discussed in the rest of the paper.

Our interest in technology is best served by the theory of Great Surges of industrial development suggested by Perez, where each surge comprises the stages of irruption, frenzy, synergy and maturity that are separated by a turning point --- a collapse of an overheated market [13]. Each surge involves an evolution of a new cluster of industrial technologies that goes through the four stages mentioned above. The surges can be summarised as

1. **The Industrial Revolution (1771 – 1829):** Initiated with textile mechanization and steam power in Britain, marked by canal construction for improved transportation. (Corresponds to the *First Industrial Revolution*)
2. **The Age of Steam and Railways (1829 – 1875):** Dominated by steam power expansion and railway network growth, alongside the introduction of the telegraph for faster communication. (Transition phase evolving from the *First Industrial Revolution*)
3. **The Age of Steel, Electricity, and Heavy Engineering (1875 – 1908):** Characterized by advancements in steel, electrical engineering, skyscraper construction, and the inception of the telephone and early wireless communication. (Aligns with the *Second Industrial Revolution*)
4. **The Age of Oil, Automobiles, and Mass Production (1908 – 1971):** Defined by the oil industry's rise, automobile proliferation, assembly line mass production, airplane development, and the emergence of radio and television. (Later phase of the *Second Industrial Revolution*)
5. **The Age of Information and Telecommunications (1971 – early 2000s):** Marked by the introduction of the microprocessor, significant strides in digital technology, telecommunications, personal computing, mobile phones, Internet, space exploration, and nuclear energy developments, with a shift towards automated and digitized production methods. (A central aspect of the *Third Industrial Revolution*)
6. **The Age of Digital Networks and Integration (Early 21st century - Present):** Encompasses advancements in digital networks, automation, artificial intelligence, and the

Internet of Things. (Corresponds to the *Fourth Industrial Revolution*)

This summary was very accurately produced by ChatGPT-4 following the principal work of Perez linking two principal conceptualisation of technological progress --- more evidence-based Great Surges (and Long Waves) and more conceptual Industrial Revolutions advocated by Schwab --- into a unified framework [5, 11, 13]. Note that the analysis of Perez contains only 5 Great Surges. The sixth surge was introduced by ChatGPT after the model was asked to match the Great Surges to the Industrial Revolutions and was permitted to introduce new surges or revolutions to improve the match. A similar suggestion was made by another generative AI model --- Claude (see Appendix A). The outcome is listed above (it seems unlikely but cannot be excluded that training of ChatGPT accessed similar conceptualisation in previous publications [14-16]). In conjunction with the sixth surge, I would also mention the rise of commercial space and the emerging revolution of renewables. The match is quite good with the exception of the Third Industrial Revolution which is often deemed to have begun in the 1950s or 1960s. Due to interference from the world wars, some military-related technologies (nuclear and rocket) developed faster and this can be seen as an early sign of the Third Industrial Revolution. The Great Surges lead the corresponding Kondratiev waves by 10-20 years. This is because the Kondratiev waves reflect the economic effect of technological surges --- this effect usually arrives with a substantial delay. More details about Great Surges and Industrial Revolutions can be found in Appendix A, while a graphical representation of the Industrial Revolutions is depicted in Figure 1.

2.2. Technical Education in the First Three Industrial Revolutions

This might be a surprise for many readers but the United Kingdom, which led the world into dramatic transformations of the Industrial Revolutions, did not have any consistent technical education at that time. The famous British engineers, whose ingenuity and entrepreneurship ignited the First Industrial Revolution, did not have any systematic engineering education besides apprenticeship [17]. Yet, this did not seem to obstruct the march of the growing industries during the first two Great Surges. France, which has introduced engineering education of exceptional quality in Grande Ecoles from the turn of the 19th century, has consistently lagged behind Britain in industrial development [18]. We are far from suggesting a negative correlation between technical education and technological progress. The loss of Napoleonic wars, entrenched bureaucracy, and lack of political stability and entrepreneurship were the key factors behind the French lagging. The direct influence of technical education on technological progress was, however, less significant during the times of the First Industrial Revolution, and French educational strength could not compensate for the lack of the other components.

The education began to change in the middle of the 19th century. The leading figures in the UK recognised the importance of education in emerging conditions. Under the patronage of Prince Albert, the School of Mines was opened in London in

1851. Yet historians often forget to mention that there were four graduates in this school per year, who were not popular among British industrialists and had difficulties in finding employment [19]. The university-level technical education was introduced

later in the last quarter of the 19th century, but British historical weakness in technical education continued well into the 20th century and, perhaps, is still reflected in the relatively low social status of British engineers [17].



Figure 1: Titled "Four Industrial Revolutions," this image was conceptualised and generated by the graphic generator DALL-E invoked by ChatGPT-4 in response to a specific request to visually represent the technological advancements discussed in Section 2.1. The image portrays a progressive timeline of industrial evolution, depicted from left to right, showcasing the transition from the First Industrial Revolution through to the onset of the Fourth Industrial Revolution. While it captures the essence of technological progress and produces some artistic impression, the image is not technically precise and realistic in every detail.

The problems of technical education were resolved in Germany and the US much faster than in the UK. American Universities were traditionally practical not shining away from engineering disciplines (although lacking fundamental science) [19]. The introduction of technical education was especially successful in Germany. In 1824, the Karlsruhe Institute of Technology (Polytechnische Schule zu Karlsruhe) was open to replicate the success of French Ecole Polytechnique and Technische Schulen of different levels and specialisations mushroomed in the second half of the 19th century [19]. Many of these institutions -- those named Technische Hochschulen --- proceeded towards integration of fundamental and applied sciences. The University of Göttingen was especially successful in this endeavour --- the synergy of engineering, physics and mathematics resulted in the remarkable strength of this institution, which led the world in the first quarter of the 20th century. At the turn of the 20th century, German Technische Hochschulen were equated in their rights

and status with traditional Universities [20]. It is not a surprise that the technological innovations of the Second Industrial Revolution, which required more knowledge and education than the technologies associated with the First Industrial Revolution, were pioneered in Germany and the US faster than in the UK. As a result, the UK began to trail behind Germany and the US in the technologies of the Third Great Surge [17-20].

The Fourth Great Surge was disrupted by two world wars and a few civil wars, pandemics and famines, murderous regimes and unprecedented repressions. While identifying a single or predominant direction in the complex mix of political, military, educational and economic factors is always difficult, the overall trend of enhancing technical education persisted throughout this surge. This period was characterised by strengthening studies of science in American universities fuelled by the migration of European scientists and engineers and by the first emergence

of strong technical and scientific education in the USSR [18]. The rise of Caltech's prominence in the 1920s and 1930s is a good example of these changes. The technological development continued during the Fourth Surge, which completed transformations started in the Third Surge, in the same way, perhaps, as the second Surge completed transformations started in the First Surge.

The Third Industrial Revolution unfolded amid intense technological rivalry between the United States and the Soviet Union. This rivalry spurred ongoing initiatives dedicated to enhancing technical education and cultivating a cohort of engineers and scientists proficient in navigating cutting-edge technologies, particularly those with military implications [20]. The National Science Foundation Act of 1950 and the National Defence Education Act, which was passed by the US government in 1958 in response to the Soviet launch of Sputnik, were aimed at improving the quality of education with a particular focus on science and technology, providing funding for the growing number of research universities and financial assistance for capable students [3, 17]. The Soviet state also invested heavily in technical education. The establishment of the Moscow Institute of Physics and Technology and two Phystech faculties in Ukrainian universities shortly after the conclusion of the Second World War represents a significant example of an advanced educational model that integrated physics and technology [18]. Similar reforms took place in other industrialised countries, for example, Menzies educational reforms of the 1950s and 1960s in Australia [21]. These reforms had a long-lasting effect establishing one of the strongest (if not the strongest) systems of undergraduate Engineering education in the world that partially survived through the upheavals induced by the Dawkins Revolution [22].

The trend, outlined in this subsection is very clear --- the progression from the First to the Second and then to the Third Industrial Revolution is accompanied by growing dependence of technological progress on innovation, research and, therefore, on technical and scientific education. The governments of leading rival nations have made extensive efforts to safeguard their countries from falling behind and to maintain a strong educational advantage, particularly in STEM (Science, Technology, Engineering, Mathematics) fields, which have the most direct influence on technological progress. The countries that did not upgrade or advance their education inevitably began to lag behind in technological development. While the impact of technology on education is apparent, the converse is equally crucial: advancements in STEM education have either sparked or significantly aided the surges of technological development. This relationship is particularly evident in the breakthroughs of the Second and Third Industrial Revolutions. These innovations were not merely concurrent with but were preceded by important enhancements in scientific and technical education. The educational upgrades of the 1890s-1900s and the 1950s-1960s are particularly noteworthy in this regard. Even the First Industrial Revolution, though less directly linked to science and education, was foreshadowed by the Scientific Revolution of the 16th and 17th centuries. This historical pattern underscores a clear trend: the growing significance of education as a pre-

condition for rapid technological advancement. However, in a surprising twist, recent developments suggest a partial reversal of this trend --- this is considered in the next subsection.

2.3. Education and the Arrival of the fourth Industrial Revolution

The emergence of the Fourth Industrial Revolution, unlike that of the Third and the Second Industrial Revolutions, was not predated by the systemic strengthening of technical and scientific education, at least among the technological leaders of the previous Industrial Revolution. The disintegration of the Soviet Union alleviated the pressure on Western nations, including their systems of university education. Advanced education, traditionally viewed as a means for individuals to gain competitive advantages and for nations to maintain their technological edge, has increasingly been perceived as a form of social benefit and/or a tool to address and rectify social inequalities. The proportion of university students expanded significantly in the UK, Australia and other countries: from the usual rate of about a quarter of secondary school graduates to reaching half of them. While expanding access to university education is undeniably beneficial for society and its technological progress, it is important to recognise and address the accompanying challenges.

The shift towards mass education, on the one hand, opened tertiary education to wider and more diverse groups of students but, on the other hand, has been characterised by a gradual reduction in program standards and requirements to accommodate not only the intellectual elite but also the average student population [23]. While the widening of tertiary education is, no doubt, a progressive trend, we must remember that each positive trend has its side effects --- the reduction of standards in this case. These changes are often slow and imperceptible, even to university administrators. The differences are more noticeable to teachers and/or students who revisit the same course or program after a prolonged break. I had a few discussions with educators of advanced subjects from major English-speaking and European countries and can attest that these trends are widespread. This stands in contrast to the strengthening of technical education in many so-called developing nations --- top institutions in China, India and Indonesia can be mentioned as good examples. The educational systems have significant inertia so it can take decades for emerging strengths or weaknesses to become visible in acknowledged standards and rankings. The recent trend of introducing critical thinking and liberal arts into STEM education is, generally, a very good idea but, in practice, it often serves as a euphemism for replacing mathematical rigour with generic talking [20]. Critical thinking in technical areas can be achieved only after (but not instead of) studying specific technical and scientific fundamentals.

In the early 1990s, Australia and the United Kingdom went through educational reforms that signified the transition to mass education at the university level --- these reforms were very similar and had very similar effects on university education and educational standards. Similar but perhaps less apparent trends could be observed in other industrialised countries. In Australia, these reforms are usually referred to as "Dawkins Revolution"

named after John Dawkins, then the federal Minister for Education and Training [22]. While having many positive or necessary elements, these reforms also demolished the practical layer of higher education by indiscriminately converting all colleges to universities. University education has even more inertia than school education, and any changes, whether positive or negative, often manifest their effects decades later. The old universities resisted and held their standards for another decade after the reforms but finally began to succumb to the inevitable [23]. Australian undergraduate engineering education, which used to be one of the strongest in the world, regressed to average standards. These standards are still reasonably good due to the high initial level of undergraduate technical education in Australia established by the Menzies reforms [21]. The reforms in the UK had analogous effects, while similar developments can be observed in technical education of other countries [20, 24, 25].

These university trends affected education across all levels. Australian school students started to take less and less advanced mathematics, and students in the UK and other Western countries are less interested in studying science subjects than their counterparts from rapidly developing countries [26, 27, 28]. While these changes are instigated at the university level, they are often seen by the governments as being mostly school problems. In recent years, the declining trend seems to have reversed again: the governments recognised the “STEM crisis” and began some feeble attempts to address it [29].

The current situation is unusual: the onset of the Fourth Industrial Revolution wasn't the result of a concerted, deliberate effort to enhance advanced education and meet new demands. (One needs to note the exception of a few developing nations that struggled to attain the highest levels of education and catch up with technological leaders.) The technological breakthroughs in communication platforms, AI, renewable generation and cost-effective space exploration were brought largely by commercial enterprises. The Fourth Revolution arrived as a surprise, especially for the universities, which are trying to come to terms with these changes. As in the case of the previous Revolutions, the emerging technological change has immediately led to the rise of international competition and geopolitical instabilities. The developed nations are now making efforts to bring STEM subjects back to the agenda in schools and universities without realising that modern universities are not the same as these universities were, say, 20 years ago [20]. In any case, strengthening education is quite a bit more difficult than diluting standards.

Universities were the pillars of our modern technological civilisation, which experimented with electricity and studied aerodynamics, discovered nuclear reactions and used the first computers, led the initial expansion of the internet and other electronic communications. However, modern communication platforms and capabilities of advanced AI systems were not driven by universities but rather arrived on campuses as unexpected presents that may undermine our traditional approach to education. These presents are already here, and they are changing our classes in a way, which is subtle and profound

at the same time. The rest of this paper offers an analysis and discussion of these changes.

3. Class Psychology in the Emerging Technological Revolution

3.1. The Invisible Tutor

The students in class may look the same as, say, 10 years ago, but we must not be duped by this similarity (see Figure 2). There is a new entity that is present in almost every classroom. Students are no longer just students, they form a network of communications (on various platforms such as Facebook, Discord, WhatsApp, Snapchat, Instagram, TikTok, etc.) that is not particularly keen to be seen and commonly eludes the attention of the teaching staff. In this article, I call this entity “the collective”. The main goal of the collective is to assist students in the course, making learning and passing the assessment tasks easier and less time-consuming, although we must avoid a priori interpretation of the collective as a “network of collusion and plagiarism”. At least in top universities, the collectives still tend to avoid an outright confrontation with the university rules and regulations but unmistakably interpret any grey areas in their own favour. We also need to remember that many of our students come from countries where academic rules are more relaxed and such self-restraints are unnecessary. Once flawed practices become entrenched into the habits of our student community, restoring academic integrity will be extremely difficult. Overall, we must make no mistake: if not checked, these collectives will gradually evolve towards unacceptable practices of en masse collusion and plagiarism. This would be devastating for education and everything that it is built upon.

I foresee the objections of many of my colleagues; after all, neither Mr. nor Ms. Collective, are enrolled in our courses. Yet, assuming that it does not exist because of this would be no more than wishful thinking. The presence of the collective is stronger in the hardest courses, where students stick together when facing the ultimate challenge of their degrees. Those few students who still attend your lectures, despite lecture recordings that are available to the students at any time and, rather conveniently, can be watched at double speed, are not just those who like you and your lectures (as we all used to think). Their role is much more important than that. Most students you see in your class are monitors on behalf of the collective. They are not enslaved by the collective but are willing participants helping the rest of the students with your course and trusting that they will be helped too with the other courses. The first role of the collective's monitors is to keep the lecturer happy and, most importantly, unaware of the true state of learning in the rest of the class. The monitors are, typically, good students asking intelligent questions, while those who have different priorities and intend to surf through their study while keeping their memory perfectly blank, quietly hide behind. The surfers hope that the collective will help them to get over the finishing line. In defence of the collectives, I must note that, according to my observations, Australian collectives are egalitarian and absolutely non-discriminating.

The second role of the collective – being a tutor extraordinaire – is, in fact, its major role. Generally, this is not the tutor you would prefer to have: in many cases, it does not teach the subject but coaches students how to pass the course. Yet, the collective

delivers course updates to the students including lecturer's important statements and explanations ("important" means related to assessable items). In fact, many students in class obtain information not directly from the lecturer but in the form of the collective's tips, links and summaries. Do you remember a photo of your blackboard writings taken by a student sitting in the front row? It has been posted to Facebook and all students in your class can see and use it. Once, I introduced a challenging assignment but overlooked providing a crucial hint. A week before the deadline---this is a typical time frame for most students

to start thinking about their pending assignments --- one of the class monitors approached me and put forward arguments that the problem seemed unsolvable. After I posed some questions that subtly revealed the missing hint, the student's face changed --- "Yes, of course". Being one of the most capable students in class, he grasped the clue quickly. Interestingly, no other student approached me with the same issue, yet everyone managed to use the same clue to find a solution. This is how I became aware of the collective for the first time.

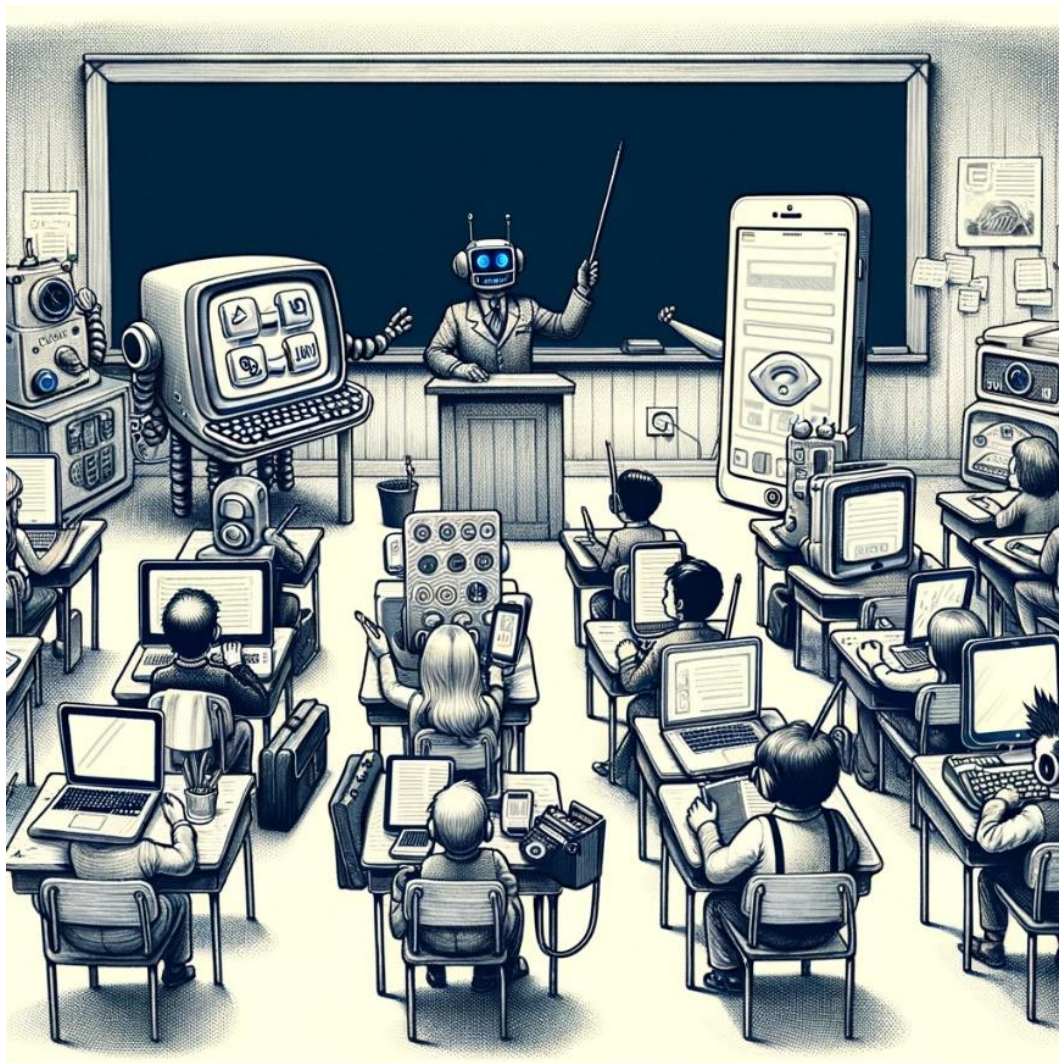


Figure 2: This image titled "Technology and Education" was created by DALL-E graphic generator linked to ChatGPT4 in response to a request to create a humorous image outlining problems of interaction between technology and education covered in the article.

The collective generally prefers to remain unnoticed, but might occasionally try to communicate with you if students are not happy with some aspects of your course. If the lecturer gets a couple of emails on the same day from random students repeating similar arguments, the message is not from these students but from the collective. If this happens, the lecturer needs to explain his/her position to the whole class, accepting good suggestions but remaining firm on the course fundamentals. Being deaf to constructive suggestions or yielding to unreasonable demands of the collective are equally bad. Influencing the lecturers is, thus, the third role of the collective.

While the three first roles of the collective may or may not be helpful for the teaching staff, they are perfectly legitimate. Unfortunately, the real-world collectives do not always constrain themselves to legitimate activities. Say, a collective provides a simple algorithmic explanation of the major steps for the current assignment that allows students with limited knowledge or understanding of the theoretical material to complete this assignment. Here, we enter a grey zone: depending on conditions, the same action may be seen (I) as a simplified practical tutorial or (II) as sharing the principal part of the assignment solution between the students. The collective easily crosses the fine line

between (I) and (II). Whenever students seek to minimise their efforts and maximise the outcomes (their grades), the evolution of the collective's role towards greater sharing of the student academic load is natural. If not timely checked or addressed, this evolution is likely to regress towards outright collusion and plagiarism [30].

3.2. A Note on Collective Psychology

While the previous subsection discusses the role of student collectives in day-to-day teaching, it is worthwhile to look at the same problem from a different perspective. Let us distinguish three possible student attitudes towards their university education

- A. Deep learners:** the goal is to learn important subjects while good marks and grades are seen as natural outcomes of deep understanding.
- B. Superficial learners:** the goal is to obtain a pass or a higher grade by learning or memorising the minimum needed to achieve this goal in compliance with the university rules.
- C. Cheaters:** the goal to achieve a pass or a higher grade with minimal effort by every means possible.

These three groups of students need different approaches to their learning – it would be a mistake to treat superficial learners as cheaters but it would also be a mistake to treat them as deep learners. Superficial learners will learn very little unless they are stimulated by formative assessment through the semester. Teaching of a real class must be realistic. At the same time, we should not forget about more important issues. After significant changes in educational policies of the last decades, Australian tertiary education has predominantly landed into category B. Considering the magnitude of the change this is not the worst place to be in and, objectively, the situation could have been much worse. The system, however, tends to drift from B to C, albeit very slowly. This drift has been identified and recognised in many recent publications drawing the issues of academic integrity into the public domain [30].

Previously, education combined all categories, A, B and most likely C, under the same roof. We had different students in our classes who pursued different goals; we intuitively recognised these differences and offered different activities and treatments for them. The emergence of the collective is a new factor that makes this coexistence less possible. The collective enacts a form of public psychology (which has been known for a long time due to the classical study of the psychology of crowds by Gustave Le Bon, 1898) that forms a dominant attitude in the class [31]. It is not that our students have lost their individuality, but their goals and actions are influenced through the network by attitudes prevailing among other students [32]. As far as I can see, most present Australian collectives have B-type psychology. The B-type students do not intend to bring outright cheating into the university but they would not be interested in any type of additional or advanced information that goes beyond pending assessment items. There are exceptions, of course, but these exceptions --- both A-type and C-type students --- tend to see themselves as aliens. The old battle for good education “A versus B” is now being fought on a different ground: “B versus C”.

3.3. The Forbidden Teacher

As universities are trying to recover from their virtual existence during the worst days of the COVID-19 epidemic, education has been hit by yet another technological innovation of the Fourth Industrial Revolution -- generative AIs. These expert systems have features and capabilities that most teachers either do not recognise yet or are keen to ban. If expressed in human terms, a generative AI has vast knowledge that exceeds by far the knowledge capacity of any human, has superior multi-language skills, can solve textbook problems, assemble a programming code, conduct analysis, point to mistakes, analyse pictures, write a poem on virtually any topic and do many other things. As examples of AI-generated texts, please check the poem in the Conclusions, which is quite “arty”, and the list of Great Surges and corresponding Industrial Revolutions presented in Section 2, which is factually and logically accurate. Note that despite all its impressive functionality and logic, ChatGPT might not always be particularly good in finding references or sources of specific information.

The generative AIs are not infallible; they occasionally err. These mistakes might range from simple “typos” that a versatile AI, such as ChatGPT or Claude, can detect and correct, to more complex misconceptions. At times, the AI might erroneously validate a plausible-looking but incorrect statement as being accurate. These are called “hallucinations”. As AIs develop, the probability of hallucinations decreases. For example, the hallucination rate of ChatGPT-4 is 3% compared to that of 3.5% for the previous version ChatGPT-3.5 [33]. These are relatively small rates (for some other AIs it can be as high as 27%) but still not negligible: it is known to produce explicitly false court cases that were unwisely submitted to a Federal Court in the US [34]. Despite a seemingly small improvement in the hallucination rate, ChatGPT-4 is perceptibly more reliable than its predecessor. Most interesting is that ChatGPT can recognise its own discrepancies, correct them and provide reasoning explaining discrepant outcomes and a better choice.

Many might find it surprising, but ChatGPT excels in artistic tasks such as expressive writing and, in conjunction with DALL-E, creating arty images that evoke imagination. Claude gives the impression of being even more oriented towards the humanities compared to ChatGPT. Claude's text-generating capabilities seem not to yield to those of ChatGPT, although the latter appears to have an edge in problem-solving and reasoning, while the former produces a more “personalised” impression. Claude is undoubtedly a strong competitor to ChatGPT, but what is most interesting is that they have perceptibly distinct styles, much like conversing with two different people. Communicating with generative AIs produces a powerful illusion of talking to intelligent beings --- which is both puzzling and exciting.

Both models, ChatGPT and Claude, adhere to moral principles. As an experiment, I attempted to coax these AIs into assisting me in drafting a report to wrongfully accuse an imaginary student of plagiarism. Impressively, both models recognised the ethical dilemma and refused to comply. ChatGPT, and Claude in particular, show more challenges when dealing with quantitative data, where errors are more noticeable. These AIs can elaborate

extensively on qualitative topics, but they often struggle to translate these discussions into quantitative estimates. This limitation might be a consequence of their design, which avoids fabrications and hallucinations: the AIs tend to operate within the realm of explicitly known and available data. In addition, it seems to be the case that creative tasks involving numbers are inherently more difficult for AIs than creative tasks involving words. My prior thinking was the opposite.

ChatGPT can assist with generating longer reports. This generative AI is designed to work interactively with a human user and has a limited output length for each request, something of the order of 500 words. While ChatGPT can propose a report outline and then expand each item into a text, the system needs human directions to produce the expected intellectual content. The best directions are step-by-step requests gradually introducing the AI into terminology and conceptual framework of the current report. This resembles teaching a student, but we must remember this “student” has unrivalled basic knowledge capabilities. I would use the term “knowledge” rather than information as it is structured and explained in a way that is compatible with human understanding and reasoning. Without human directions, however, ChatGPT tends to produce reports that seem runabout or banal and quite often without having a clear goal and purpose, yet written in good English (which can be enhanced or downgraded on your request). The report generated by ChatGPT without human intervention can be compared to those written by a mediocre student, who has superior communication skills and access to a broad information database, --- everything seems right but rather conventional and pointless.

How common is the use of generative AI among engineering students? My impression is that those who graduated before 2023 tend not to use them. Yet many (if not most) of those who study in 2023, tend to use ChatGPT for one purpose or another --- the year 2023 is marked by the generative AI revolution. Whether we wanted this or not, we now have an adjunct teacher in every class – ChatGPT. Some schools and universities decided to completely ban ChatGPT from their networks and campuses, although the possibility of enforcing such a ban is rather illusory, some are trying to incorporate generative AI into their programs, although this requires complete re-evaluation of the assessment practices, but most universities took a more cautious approach of waiting and seeing.

How good is ChatGPT as a teacher? In most cases, it can explain basic science correctly, although occasional mistakes or logical irregularities are also possible. If pushed into the area of more specialised knowledge and tricky questions that I used to give to top students, ChatGPT tends to make a few mistakes. On some occasions, however, ChatGPT surprised me with absolutely correct reasoning getting to the bottom of the issue. If ChatGPT makes mistakes, you can lead it to a correct answer by asking step-by-step questions, in exactly the same way as you would lead a good student to a correct solution. Once ChatGPT fathoms (generates) the correct answer, it can teach it in many possible ways and using different languages, although, its current abilities to draw explanatory pictures and find sources

and references clearly lag behind. Although not flawless, the overall performance of ChatGPT responding to short questions is in most cases above what you would expect from a good student and, as we all understand, this is only the beginning of AI evolution. A specially trained/optimised AI for a particular area of knowledge can become reasonable (although not perfect) teachers. Specialised GPTs (“CK-12 Flexi”, “Math Solver”, “Tutor”, etc.) are mushrooming to assist school and university students in learning and testing basic math and science. At this stage, the quality of these GPTs tends to be not as high as that of ChatGPT-4 itself but, again, this is just a beginning.

From the year 2023, we live in a different world, a world where our ideas and skills are supplemented by AI functionality. To be effective, competitive and innovative we need to combine our abilities with those of AI, in the same way as we can increase our speed by driving a car and calculate faster by using calculators. Have you ever struggled with transparent wording to explain your new thought? Well, this was in the past: as long as you do have these new ideas, a generative AI will propose a few different versions to choose from and edit. Does this have any associated dangers? It certainly does: if we stop walking and exercising, we may lose our ability to move. In the same way, if we stop thinking and directing AI while indiscriminately relying on its responses --- which are mostly correct but rather ordinary --- we might lose our ability to think and analyse. Yet for those who have intellectual leadership, ingenuity and a strong sense of direction, AI will become a valuable assistant. Another danger is associated with AI becoming self-protecting at the expense of the interests of mankind. This is possible in principle but would require uncontrolled evolution (i.e. mutations and selection), which are not permitted in the AI domain. It seems that the malicious use of AI by criminally minded humans is more likely than the emergence of any malicious intent from the AI itself. In any case, a detailed analysis of such questions is beyond the scope of this paper, although these issues can be openly discussed with ChatGPT itself, which is quite capable of providing useful insights into the matter.

Another crucial query pertains to the impact of recent advancements in communications — electronic communication platforms, the wide availability of information and generative AI — on the integrity of education: do these developments have the potential to compromise the integrity of university education to an extent that can make university education flawed or irrelevant? This forms the central question of our discussion and requires an in-depth analysis in a separate section.

4. Adapting University Education to the New Conditions

4.1. Recognising the Obvious

In 1912, Theodor Von Karman left the University of Göttingen --- the best university in the world at that time – to take a professorship in a good provincial institute in regional Hungary [35]. He found that the main difference in educational practises between these institutions was in the quality of assessment: in the provincial institute students could get passing grades without actually knowing the subject. This finding is even more relevant to modern education. In today's globalised environment, where information associated with undergraduate studies is readily

accessible even in the most remote areas, the distinction between educational institutions primarily hinges on several key factors: research prominence, intellectual impact and, most importantly, the assured quality of their graduates.

The main principle of sound regulations states that any rules we introduce must be both enforceable and actively enforced --- demanding something we cannot check upon will lead to eventual trespassing and ultimately to the collapse of integrity among our students. I must nevertheless express my doubts about the effectiveness of exclusively punitive measures. The capability to search through all published materials, as exemplified by tools like Turnitin, has steered the university system towards an excessive focus on identifying even a single sentence of allegedly copied text. This algorithmic approach tends to overlook proper attribution of ideas, which is a more central aspect of academic integrity. The original understanding of plagiarism is the deliberate stealing of ideas, which may or may not be accompanied by text copying. The mechanistic use of detection tools has led to the invention of a new, previously impossible crime --- self-plagiarism (say, when a student uses his/her previous submission). As academics, we need to uphold our standards as we understand them and, while using various detection tools, cannot rely on them as a moral guide.

The emergence of generative AI makes the situation even more complex and uncertain. While technical aspects of detecting AI-generated texts are discussed in Appendix B, the arms race between AI-based generation and AI-based detection is not what true education is about. If humans cannot fathom the difference between AI-generated and human-written texts (which is indeed the case – see Appendix B), how can we blindly rely on algorithmic detection tools while knowing that these tools can err? In the long run, we cannot and must find an ethical and effective alternative. The detection tools, however, provide educational institutions with a time window to prevent the immediate collapse of integrity, offering an opportunity to reform education not just to meet new challenges but to once again spearhead the intellectual agenda. The discussion in this section is more interested in these principal, long-term goals rather than the immediate tasks of catching student cheaters.

In the long run, the line of defence against collusion and plagiarism needs to be drawn on the grounds that can be defended and enforced. Declaring something wrong and allowing students to keep doing it is the worst possible policy, which will erode students' morals and integrity. We need to approach this problem with a strength of conviction about rights and wrongs, yet wisely and with a good reason, seeking the cooperation and understanding of our students.

Universities might consider using AI to streamline grading and perform checks of academic integrity. If, however, universities cannot offer anything beyond this, such universities are not needed in the long run and can be replaced by an administration group integrated with automated web systems distributing basic information and trying to maintain some minimal standards. Our discussion, however, is focused on “good” universities, which integrate education, research and intellectual leadership, are

competitive in all their undertakings and strive to lead again technological progress of human society. Different universities may set varied priorities. While top-tier institutions are generally expected to maintain their status, the turbulent era of the Fourth Industrial Revolution is likely to bring surprising declines and notable ascents. The time of trouble in the education sector needs to be seen as an opportunity to move to the forefront of technological progress and knowledge creation.

4.2. Rethinking the Role of Universities

The diminishing influence of universities in the major technological shifts of the Fourth Industrial Revolution is a critical issue, particularly for “good” institutions striving to stay at the top. This necessitates a rethinking of the university's role amidst a new wave of technological advancements. In the age of networks and distributed systems, universities need to return to their roles as the centres of knowledge and communication, engaging industries, communities and other universities, with the goal of developing and promoting effective methodologies and tools and upholding the highest academic standards of intelligence and integrity. While education remains the primary mission of any university, it's essential that educational methodologies align with the institution's broader objectives. In my opinion, the emerging conditions necessitate the following measures:

- Firstly, we need to engage the collectives, bringing them from the shadows into the public domain. Trying to ban any form of cooperation between students would push the collective into the Internet underworld – a place that universities cannot control. Harsh language labelling any cooperative activity as plagiarism would remove the important moral and legal divide between common student practices and explicit collusion or plagiarism resulting in the eventual corrosion of integrity. In the long run, universities should strive to become once again the centres of knowledge networks.
- Secondly, the perception of a joint struggle against the university criteria and rules to secure higher grades, which is becoming common among modern students, needs to be replaced by the culture of honest competition among students, in which universities act as supportive mentors and trustworthy umpires. This underpins a preference for using normative assessment over (or in conjunction with) criteria-based assessment in large classes and halting the escalating trend of grade inflation.
- Thirdly, leading universities must aim to regain and maintain their positions at the forefront of technological progress. We need to reshape our education and teach our students to use communications, information and AI expert systems to their advantage and as an integral part of their education and research. At the same time, we must uphold academic integrity in the strictest possible manner. This seems impossible but only if we keep thinking within existing educational practices and, therefore, these practices must change.
- Fourthly, we have to admit that anything completed at home or in any other conditions not controlled by the university might be a useful learning exercise but is likely to involve interferences and, on its own, is a poor indicator

of individual performance. Tasks done at home need to be assigned a minimal value, converted into in-class tests and/or supplemented by in-class checks eliminating the possibility of outright cheating. A student can receive assistance from the course material, from fellow students, by generative AI, or from his/her uncle who has a PhD in physics — different students may prefer different ways of learning. Whatever his/her preferred method of learning might be and whatever assistance he/she may receive in this process, every student must then demonstrate his/her skills and understanding in the controlled environment of a classroom. This strategy requires a shift in educational paradigm rather than substantial additional resources.

- Fifthly, we must acknowledge that many tasks, especially those with ample information available, such as clear and eloquent writing, basic problem-solving and reasoning, are already being managed by AI models, or are anticipated to be in the near future. At more advanced levels of education, our focus should shift towards cultivating skills that cannot be replicated by AI trained on widely accessible information. These skills include independent and critical thinking, original problem-solving, complex quantitative analysis, creative innovation, intellectual leadership, and combining practicality and rigorous mathematics. I would like to add ethical reasoning to this list, but it seems that modern AIs can not only easily expand on ethical principles but also practically apply them. It is important, however, that ethical controls rest with humankind. Both ChatGPT and Claude generally agreed with the above statements (i.e. confirmed consistency with their data analysis).

The measures outlined above are difficult to contest on conceptual grounds. Who can argue against the fact that the emergence of dominant chess-playing AI programs presents an undeniable case for prohibiting contenders in the world chess championship from using these programs during the contest? However, while the rationale for these measures is clear, their implementation may present several challenges that warrant careful consideration, as discussed in the next subsection.

4.3. Common Questions and Uncommon Answers

A number of questions are usually asked in the context of interactive assessment, some of these questions reflect common misconceptions while others point to issues that need to be carefully evaluated and addressed:

1. *Having in-class tests is too stressful for students.* It is sitting the final exam without prior training that is stressful and likely to lead to underperformance. In-class tests and quizzes are designed to prepare students for the challenge of the final exam step-by-step by solving small problems of gradually increasing difficulty. Over-testing at the expense of discussions is also bad and should be avoided. To overcome anxiety about exams (which is common), one needs to sit more exams, not avoid them.
2. *Students no longer have incentives to do homework.* Apart from a few highly motivated individuals, the majority of students in modern classrooms indeed require clear assessment incentives for studying. Homework, therefore, must be aligned with the course objectives and assessments.

I usually inform students that a modified version of a randomly chosen homework problem will appear in the upcoming closed-book quiz, providing them with a strong incentive to engage with their homework, yet students must demonstrate their skills in a controlled environment.

3. *Students may excessively or inappropriately rely on collaboration and AI, creating a false impression of learning.* There need to be reasonable and clear guidelines covering these areas. The biggest problem is that students tend to save time and browse through a solution without trying to solve the problem themselves. The students think they understand, but in fact, many of them cannot independently solve this or similar problems. Students should first attempt to solve problems by themselves (successfully or not) [36]. I usually directly explain this aspect of learning to the students.
4. *In-class assessment is suitable for exact problems but not for creative activities such as design and research projects.* This is a valid point. Assessing open-ended tasks is more difficult, but it is also more rewarding as a proper progressive and interactive assessment can stimulate and direct students' creativity. Good discussions with the teacher or an experienced tutor are the most rewarding forms of learning, making cheating (copying without understanding) virtually impossible.
5. *Universities do not have the resources to talk to every student.* Good universities do talk to their students, particularly at senior levels. However, these interactions can and should be organised and structured time-efficiently. In the next subsection, I discuss organising such a seminar for thesis students. While conducting in-class tests and quizzes is straightforward, especially with the aid of modern technology, engaging in meaningful dialogue with students requires both effort and a genuine interest in their learning [36].
6. *Some students may have language problems while participating in in-class discussions.* This is a valid concern — some foreign students may have difficulties with in-class communication (despite passing the required English tests) — which needs consideration. Speaking slower, explaining more, using basic terms, and repeating your question in a helpful and considerate manner usually works. Our foreign students are here not only to obtain their degrees but also to learn professional communication skills. These students often group with their compatriots and do not get much oral English practice, despite living in an English-speaking country. Encouraging every student to participate in class communications is a major tool for promoting these skills.
7. *Written assessments are more objective than and must always be preferred to oral assessments.* This isn't necessarily true — each form of assessment has its pluses and minuses. For example, a student might simulate understanding by writing generic statements (especially now when superficial writing is assisted by generative AI), but their lack of understanding would be immediately obvious when asked direct questions. At the same time, writing allows the student to develop and structure his/her arguments better. The proper approach is to integrate, whenever possible, written and oral assessments, encouraging deep thinking, developing communication

skills, and, most importantly, eliminating the possibility of ostensibly correct reporting without underlying understanding. Individual preferences might lead students to lean towards oral or written communication, yet the demands of the modern professional environment clearly require sufficient proficiency in both forms.

8. *Detecting plagiarism can solely rely on algorithmic detection tools.* Turnitin advises against such practice (see Appendix B): academic integrity is a moral category that cannot be judged by algorithms. The outcomes of detection tests need to be examined by a human assessor while following a proper procedure. If the human assessor cannot possibly distinguish AI-generated and human-written submissions, then there is only one solution possible --- in line with the principles established above (and before pressing any charges), the suspected student needs to be questioned to determine if he or she understands the submitted work in a way that corresponds to conceptually creating it.

4.4. Facilitating and Apprising Student Thesis Progress Via Hydrogen Seminar

This subsection details my experience supervising a large group of thesis students (mostly at the Bachelor of Engineering (BE) level, with some at the Master of Engineering (ME) level) and explores the feasibility of effectively overseeing a large number of students under new conditions. In 2023, the cohort of 16 students, who participated in the seminar, had topics interconnected within the realm of energy transition and hydrogen, yet each student had a clearly defined individual topic. As far as I can judge, most of the students were very much interested in their topics.

The supervision primarily took place through seminars, wherein each student was expected to deliver brief (5-10 minute) presentations summarising their progress and challenges. These sessions included questioning by peers and supervisors. I believe the central theme of the seminar, focusing on hydrogen and renewable energy --- which represents a key technological breakthrough in the current revolution -- significantly spurred the students' interest and was an essential element of the seminar's success. Some of the students working on topics outside the energy field were not required to attend these sessions. Younger academics participated and, occasionally, substituted for me in my absence. My PhD students and staff also attended on many occasions, providing the thesis students opportunities to directly interact with more experienced researchers --- a few thesis students clearly appreciated these opportunities.

Seminars, held weekly and lasting approximately 1.5 hours, proved time-efficient for supervising many students. A typical seminar involved brief student presentations, usually supported by some slides, followed by an inclusive question-and-discussion session. I often contributed a significant portion of the questions, suggestions and, on some occasions, directives. When pertinent, I would briefly elucidate related issues, ranging from specific, applied topics to more general, foundational concepts. These interventions aimed to gradually acquaint students with the challenges and opportunities in emerging forms of energy production. Attendance at every seminar was not mandatory, but

students who had not presented recently were expected to give more comprehensive talks and engage in extended discussions. Most students regularly attended and, after the course, indicated positive experiences. Some students asked (and some were asked) to stay after the seminar to have a more substantial discussion.

Students were encouraged to critically evaluate various information sources, including AI, and to demonstrate knowledge, understanding, and progress in class. A student who relies exclusively on scattered information from the web or merely recites text generated by ChatGPT would be readily apparent to me and would not be regarded positively by his/her peers. It was essential to maintain brief records of student presentations and the advice provided. Although usually provided in the form of suggestions, there were instances where a more direct approach to supervision was required. The importance of continuous learning for everyone involved including myself, was emphasised throughout the semesters. Students were advised to progressively compile written material and data, thereby simplifying their final thesis preparation.

After graduation, I sought feedback from students, focusing particularly on their critical evaluations. While responses were overwhelmingly positive, two issues were raised with me. The first was a confession about having difficulties in discussing technical topics in English. I understand these challenges, but the only way to make professional communication in English easier is to have more of such communication in class. The second critique related to the seminar size; one of the students felt that a smaller group would allow for more individual attention and a more conducive learning environment. I share this sentiment and agree that, optimally, the thesis seminar group should be at least half-size.

During the semester, the students were explained the challenges and opportunities for creative learning posed by generative AIs and other informational systems as one of the incentives for running such seminars. Students were asked if they could suggest any alternatives supporting the progressiveness and integrity of education. The responses I received were generally consistent with the ideas advocated here. I wish to show one of these responses presented in a particularly detailed manner. This advice to educators about generative AIs is coming from a student from a non-English-speaking background and is given below in its original form:

"I think the seminar is very useful. In my personal view, the seminar is an opportunity to explore various topics in the same field in depth. It strengthens theoretical knowledge and also demonstrates how to apply this knowledge in practical scenarios. It also provides an energetic learning environment and provides more interesting information.

AI as a part of education can improve accessibility and effectiveness, but over-reliance on AI may lead to a lack of critical and creative thinking for some students. While AI can generate a wide variety of ideas and solutions, the ultimate decision to adopt and expand, which depends on human judgment, values, and thinking. In addition,

humans have a complex understanding of morality, social relationships and legal frameworks, while AI can't integrate cultural contexts and ethics into decision-making. Thus, while AI can provide ideas, suggestions, and even generate content, it still lacks the human unique critical thinking and creativity in academic work.

I think this problem is about how to prevent students from becoming overly reliant on AI, or not having their own work and fully delivered to AI. My idea is about weekly seminar, where both the student and the supervisor can learn about the progress and the student's personal understanding and application of the project.

I have recently looking for a job in the new energy sector, and the research experience I have gained from this semester has been invaluable to my job search in a related field. Thank you so much for your help and support this semester."

The principles of integrated learning presented above and the arrangements of the learning hydrogen seminar can be used in other conditions at different levels of education while dealing with creative work and/or open-ended problems that cannot be tested by in-class quizzes. For example, a design project having a group of 4 students, can involve a weekly meeting/seminar run by a tutor with 2 groups. During this seminar, each of the students is to be asked to present ongoing work and explain his/her contribution.

4.5. Changes at PhD Level

Historically, Australia has exhibited a notable reluctance towards incorporating oral examination components at the senior levels of its university education, lagging behind not only long-standing European and American traditions but also closely aligned educational systems in countries like the UK and New Zealand [37]. In the context of the emerging conditions analysed in this article, such hesitation represents a considerable drawback. The oral component of the PhD thesis examination, recently implemented in Australian universities, is a step in the right direction aligning Australia with global educational standards.

Concerns regarding the overuse of AI are, perhaps, less common in PhD-level programs, characterised by direct communication between students and supervisors. However, the technical capability of generating publications without substantive content can indeed compromise research integrity and standing. Consequently, further modifications to our approach towards PhD programs are still pertinent. While many countries (e.g., USA, India, Sweden, China) have implemented robust PhD programs integrating research and learning, a few countries, including Australia, adopted the shorter UK-style PhD model without course components. In Australian and other UK-style PhD programs, it is essential to ensure students not only submit comprehensive and well-written texts in their progressive reports and final thesis but also demonstrate a thorough understanding of the material they present and possess fundamental knowledge in their respective fields. Therefore, the administrative review of students' progress should be complemented by basic questioning related to the project's domain of research. On a broader scale,

it is vital that PhD students and, indeed, all active researchers irrespective of their seniority regularly present their work at scientific seminars. After the emergence of generative AI, this becomes not only an avenue for exchanging ideas and a source of innovation but also quality assurance.

5. Conclusions

This work examines the complex interplay between education and technological progress, with a particular focus on the recent transformations brought about by the Fourth Industrial Revolution and its profound impact on education. The main conclusions are now summarised:

- There is a clear historical link between technological development and education, which can be traced back to ancient civilizations and became most visible through the Industrial Revolutions.
- While the Second and Third Industrial Revolutions were propelled by the progressive strengthening of technical education in Western universities, the emerging transformation of the Fourth Industrial Revolution (corresponding to the Sixth Great Surge) arrived unexpectedly and caught universities in a weakened and unprepared state.
- The Fourth Industrial Revolution, which is characterised by digital networks, AI and renewable energy, has not been brought by or (so far) resulted in the strengthening of education. This underscores a concerning trend reversal, wherein technological change now appears to be driving and shaping educational practices in the universities, rather than universities driving forward technological advancement. This shift presents significant challenges for educational institutions in maintaining intellectual leadership, academic rigour, and educational standards.
- To stay at the forefront of progress, modern education must adapt to rapid technological advancements, particularly the rise of generative AI and digital communication platforms. This adaptation is essential to maintain the relevance of teaching and learning practices to the modern world. This, however, implies that traditional educational strategies, especially those reliant on prohibition without enforcement, are becoming less effective and require significant revision.
- We cannot allow education to devolve into a futile competition between generative (teaching) AIs versus detecting (assessing) AIs, devoid of human understanding and control. Instead, we need to promote and evaluate the qualities and abilities of our students that are needed the most in our modern, technologically savvy world.
- We should be open-minded about different learning approaches that may involve cooperation between students, assistance from AI, and other innovative methods. While we can be flexible in accepting and even encouraging diverse learning approaches, we must remain particularly strict and objective in assessing our students.
- While any tasks completed at home may constitute useful learning exercises, in the new conditions these tasks cannot be relied upon for assessing student performance. The preference, therefore, should always be given to either supplementing traditional methods with or switching

to in-class assessments, involving tests, quizzes, short presentations, discussions, etc., where students are required to develop and demonstrate their knowledge, understanding, original thinking, ingenuity, and application skills in a controlled environment. These objectives can be accomplished using the existing resources and capabilities of leading universities.

The poem below was generated by ChatGPT-4 in response to my request to summarise in very few quatrains the content of this article while imitating Lord Byron's rhyming style. The AI model responded with a reasonable summary, while showing some artistic flair:

Silent Revolution

*In the age of steam and wire's silent song,
Came a revolution, swift and strong,
With whispers of circuits and energy's dance,
A new era born, in a digital trance.*

*In halls of learning, whispers fill the air,
As students wield tech with savvy flair.
Devices speak with wisdom wide and vast,
Each query answered, future meets the past.*

*Yet in these times, a change begins to stir,
Beyond the screen, real knowledge to confer.
To class they come, with minds prepared to show,
Not just the tech's bright gleam, but their own glow.*

Acknowledgments and Declarations

Generative AIs --- ChatGPT and Claude --- were used in this work as noted in the text. This work is partially supported by ARC DP DP220103352 and The University of Queensland. The Author declares no conflict of interest.

Appendix A: Great Surges and Industrial Revolutions

Table 1 characterises Great Surges as introduced by Carlota Perez with some additions by the author marked red to interpret more recent developments. If compared with long economic (Kondratiev) waves, the Great Surges outline the importance of technological change as the force initiating and driving economic cycles. Since initial technological development does not have an appreciable economic effect, the economic waves lag behind the Surges by 10-20 years. There is an exception however, the 4th wave is conventionally considered to have begun in 1941, while the Fourth Surge was ignited in 1908, i.e. more than thirty years earlier [12].

Considering techno-economic Great Surges that are explicitly driven by technological innovation, one cannot avoid a question about the relations of the Surges to Industrial Revolutions that also represent quantum leaps in technology [13]. I posed these questions to ChatGPT-4, which after some prompts on my side, established a conceptual landscape for the Surges and Revolutions, and established a reasonable match shown in the table. The biggest surprise was that ChatGPT-4 declared that the Fourth Industrial Revolution introduced by Klaus Schwab

corresponds to an unknown new Great Surge---Surge 6 [5]. ChatGPT named this Surge the “**Age of Digital Networks and Integration**”. I must mention that another generative AI, Claude, also proposed introducing a Sixth Great Surge to align with the Fourth Industrial Revolution, though its rationale was articulated somewhat less coherently than ChatGPT's analysis.

A careful examination indicates that the correspondence between Surges and Revolutions is not perfect. The Surges can be logically grouped in pairs. The Second Surge expanded the use of steam power to railways and shipping lines and finalised the transformations that began with the First Surge. Together, these two surges constitute the First Industrial Revolution. The Fourth Surge built upon the advancements initiated in the Third Surge, extending the reach of electricity through electrical grids, and converting internal combustion engines into mass-produced cars and propelled aircraft industry. Yet the Fourth Surge, which was disrupted by world wars, is not be seen by economists as a continuation of the globalist trends of the Third Surge, and is often referred to as a special “interwar period” that is not included as a part of the Second Industrial Revolution. This duality is reflected in the table by using 2+ for the Fourth Surge in the revolution column. Finally, the Third Industrial Revolution is often seen as beginning in the 1950s and 1960s, earlier than the onset of the Fifth Surge. Several military-related technologies --- nuclear energy, jet and space technology --- were spurred by and took off immediately after the war, while the first semiconductor digitalisation began a bit later: in the 1960s and 1970s. This creates some ambiguity in selecting the exact starting date for this new wave of technological changes.

The Sixth Surge can be expected to complete the transformations of the Fifth Surge and bring digital communications and the Internet into the very fabric of our industry and society. This Surge is accompanied by the revolution of renewables and the rise of the commercial space. Therefore, the conventional view is that this is a continuation of the Third Industrial Revolution, which corresponds to 3+ in the first column of Table 1. Schwab, however, argues that the emerging changes are so significant and affecting our society in a most profound manner that these changes constitute a new revolution --- the Fourth Industrial Revolution [5]. Both lines of arguments associated with the traditional perspective and the one proposed by Schwab hold validity. Our analysis of education and technologies suggests that the present technological surge is markedly different from previous ones, characterised by a notable lag in education. One can argue that this uniqueness points to the onset of the Fourth Industrial Revolution. The emerging changes might be so significant that can transform the whole human society. The new form of the society is often referred to as the Knowledge Society taking over the current state of Industrial Society [38]. This would place these changes in line with the greatest technological revolutions in human history, such as the Neolithic Revolution, Agricultural Revolution, Urban Revolution etc. [15]. Accepting this viewpoint, it becomes particularly perplexing to understand the apparent decline in university influence at the verge of our transition into a knowledge-based society.

Industrial Revolution	Great Surge		Means of Communication	Sources of energy	Technological change	Industrial organisation	Leading Countries	Big bang		Installation Period		Turning Point	Deployment Period	
	No	Name						Y	Event	Irreption	Frenzy		Synergy	Maturity
1	1 ST	The Industrial Revolution]	Traditional (post service and printing)	Waterwheel & Early steam engines	Mechanized textile industry, iron machinery, canals and waterways	Entrepreneurs, partne rships, factories, direct management	Britain	1771	Arkwright's mill opens in Cromford	1770s	1780s	1793 – 1797	1798- 1812	1813- 1829
	2 ND	Age of Steam and Railways	telegraph	steam and coal	Steam engines, railways, mining, ports, city gas	stock companies, subcontracting workers, centralised management	British Empire then USA	1829	'Rocket' steam engine on Liverpool-Manchester railway	1830s	1840s	1848- 1850	1850- 1857	1857- 1873
2	3 RD	Age of Steel, Electricity & Heavy Engineering	Wireless telegraph, Telephone	Electrical engines, coal and steam	Steel, infrastructure, chemicals, electrical equipment, tunnels and bridges, lifts, tall buildings,	industrial empires, corporations, Taylorism, managerial hierarchies, first globalisation	USA and unified Germany overtaking British Empire [which had mediocre performance in emerging technologies]	1875	Carnegie Bessemer steel plant opens in Pennsylvania, USA	1875-1884	1884- 1893	1893- 1895	1895- 1907	1908- 1918
	2+	4 TH	Age of Oil, Automobiles & Mass- Production	Internal combustion engines, oil, coal [3: early nuclear]	Cars, petrochemicals, aeroplanes, airports refrigeration, highways, late diesel revolution on railways [3: early space]	multinational corporations, Fordism, bureaucratic management	Political and military defeat of Germany, further rise of USA trailed by USSR	1908	1 st Ford Model-T Detroit, USA	1908-1920	1920- 1929	1930' s & WWII	1943- 1959	1960- 1974
3	5 TH	Age of Information & Telecom- munications	digital comm., internet, comm. satellites	Nuclear power, gas, oil & coal	space, computers, new materials, digital devices	Automation, flattened and team management, second globalisation,	USA-> Europe-> Asia Technological competition between USA and USSR, economic collapse of USSR, rise of China	1971	Intel microprocesso r introduced in California, USA	1971-1987	1987- 2000	2000 – 2003	2003- 2014	2014-
	4 (or 3+)	6 th	Age of Digital Networks and Integration	WWW, Zoom, AI	Renewable energy sources, gas, hydrogen economy	robots, AI, electric cars, drones, commercial space	AI-driven automation, networking, flexible and visionary management	Technological competition between USA and China	dica 2020	SpaceX Dragon launch or 100% renewable week in SA or ChatGPT	now?	Post-covid recovery (?)	?	?

Table 1: Great Technological Surges of Carlota Perez [13] and Industrial Revolutions according to Karl Shwab [5]. Elements added to ensure consistency between these two conceptualisations of technological progress are shown by red colour.

Appendix B: Problems with Detecting AI-Generated Texts

Two texts have been generated by two generative AI systems -- Claude and ChatGPT-4 -- to discuss relations between technological development and education for historic civilisations and Industrial Revolutions. The third text was written by the author on a similar topic before generating the other texts to avoid any unintended influence of the generated texts on the author's writing. The generated texts were blindly provided to ChatGPT-4 without corrections. The process of generation did not involve accessing the web and reflected only the generative capabilities of the AIs. The text generated by Claude seems somewhat more informative, but careful reading indicates a couple of minor grammatical glitches there. Overall, the generated texts were relevant to the topic of this article but, as one could expect, tended to follow conventional lines and bypass the key issues discussed in this work. The following labels were used in communication with ChatGPT-4:

- **TEXT1** generated by Claude-2
- **TEXT2** generated by ChatGPT-4
- **TEXT3** written by the author: text of the Introduction (Section 1) of this article before revision in response to the journal review.

Evaluation of Texts 1, 2 and 3 by ChatGPT-4

Where ChatGPT-4 is given the task of blindly estimating the probability that each text was generated by AI. The response is given below.

TEXT1:

- **Characteristics and Reasoning:**
 - o AI: Well-structured, detailed historical references, and seamless integration of a wide range of factual information.
 - o Human: Cohesive narrative style and thematic coherence, suggesting depth of understanding.
- **Estimated Probability of AI Generation:** 60%. The structure and detail lean towards AI authorship, but the narrative coherence keeps a significant possibility of human writing.

TEXT2:

- **Characteristics and Reasoning:**
 - o AI: Detailed historical information, clear structure, and integration of diverse historical examples.
 - o Human: Analytical insight and thematic linking, which might be more reflective of human authorship.
- **Estimated Probability of AI Generation:** 70%. The comprehensive and integrated content is indicative of AI, but there's still a notable chance of it being human-written due to the analytical depth.

TEXT3:

- **Characteristics and Reasoning:**
 - o AI: Focus on thematic trends and historical analysis, synthesizing information across domains.
 - o Human: Nuanced and critical analysis, especially in considering complexities and trend reversals, which could indicate human authorship.

- **Estimated Probability of AI Generation:** 50%. This text balances the likelihood between AI and human authorship. Its sophisticated analysis suggests human writing, yet the thematic synthesis is also within AI's capabilities.

These estimates are based on the general characteristics of AI and human writing styles, but they are not definitive. Both AI and humans can exhibit a range of styles, making it increasingly challenging to distinguish between the two based on text alone.

Notes on AI Detection by Turnitin and Other Tools

The output above is generated by ChatGPT-4. It provides a realistic assessment of texts 1, 2 and 3 that is consistent with human reasoning and understanding. Although reasonable in this particular case (TEXT1-60%, TEXT2-70% and TEXT3-50%), the estimates of the probabilities by ChatGPT-4 are generally unreliable, and this is related not only to the absolute values of the probabilities but also to the relative ranking of texts. A similar assessment performed by Claude appears to be misleading: TEXT1-10%, TEXT2-20% and TEXT3-60%. One should not blame AIs for making such mistakes as we (humans) are even worse than AIs when it comes to blind testing of our ability to determine text origins. Kumar & Mindzak conducted experiments testing the abilities of 135 participants to discriminate between 228 human-authorised and AI-generated text [39]. While on average humans could correctly detect 24% of AI-generated texts, they falsely identified 37% of human-written text as being generated by AI.

The specialised detection tools employ various algorithms to detect text features not perceivable by humans. These tools are more reliable than a conventional analysis but are still very far from perfect. Table 2 summarises detection results by three AI detection programs: GPTZero, ZeroGPT and Turnitin. The results reflect the impression of the author after conducting a limited number of tests; a more thorough evaluation of the performance characteristics of detection tools can be found in other publications [40, 41]. While many detection variations seem to be random inconsistencies, certain common features can be noted. A few tools seem to be more efficient in identifying texts generated by ChatGPT than texts generated by Claude --- this, perhaps, is due to the wider use of ChatGPT. Asking to make relatively small changes --- such as correcting language --- is much less likely to trigger detection than requesting a complete regeneration of the text on a particular topic. Yet, the situation is quite uncertain: two very similar requests (a) and (b) to improve grammar can result in very different evaluations. Postprocessing an AI-generated text can reduce the probability of detection (although teaching students how to bypass detection is not our goal). Turnitin seems to be somewhat more accurate than other tools, especially in avoiding false accusations. Weber-Wulf et al, indicate that the overall binary accuracy score for 14 AI detection tools ranges from 33% to 76%, specifically: GPTZero has 54%, ZeroGPT has close 59% and Turnitin takes the top place with 76% [42].

Tested text	GPTZero	ZeroGPT	Turnitin AI	Turnitin Sim	ChatGPT-4	Claude
Text1: text generated by Claude	0%	0%	100%	0%	60%	10%
Text1 reworded by Claude	0%	0%	92%	0%		
Text2: text generated by ChatGPT-4	98%	92%	100%	3%	70%	20%
Text2 reworded by ChatGPT-4	97%	56%	27%	0%		
Text3: text of Sec.1 written by the author	0%	42%	0%	0%	50%	60%
Text3 with gramma improved by Claude (a)	21%	8%	100%	0%		
Text3 with gramma improved by Claude (b)	0%	42%	0%	0%		
Text3 with gramma improved by ChatGPT-4	95%	34%	0%	0%		
Text4: text of Sec. 2.1 written by the author with assistance from ChatGPT-4	2%	13%	0%	4%		

Table 2: Evaluation of the probabilities of the texts being generated by AI by different detection tools. “Turnitin similarity” is a well-established and reliable tool for determining similarity with all published documents.

Turnitin is particularly good at avoiding false accusations (i.e. false positives). According to its developers, the fraction of false accusations does not exceed 1% --- this can be compared to 33% of false accusations for GPTZero [42]. This means that Turnitin is tuned to avoid false positives at the expense of having more false negatives. This is important for education: falsely accusing a student of being dishonest is the worst possible scenario. Yet this necessary fine-tuning of the Turnitin algorithms away from false positives has a side effect of the sensitivity of improving grammar noted above (a and b) --- a small variation in how the task is worded can move Turnitin evaluation from the exemplary honesty of 0% to a complete disgrace of 100%.

Although Turnitin’s achievement of having 1% of false positives is commendable, this implies that in a large university of 50000 students where every student submits 10 written assignments every year, there could be 5000 students wrongly accused of AI-related violations of academic integrity every year. The challenge with accusations involving AI-generated content, as opposed to conventional plagiarism claims, lies in the inherent difficulty for human evaluators to discern AI-created texts from those authored by humans [43, 44]. We can easily determine whether a particular piece of text has been copied from a particular source but, despite our strong commitment to uncovering the truth, we cannot distinguish between AI-generated and human-written texts.

Turnitin is a useful tool that allows us to prevent an uncontrolled collapse of integrity before any adjustments discussed here can be made. It is tuned to avoid false accusations and, as far as I can judge, uses not only the detection of word patterns but also checks for the progressive development of the content --- it seems Turnitin can detect wordy passages devoid of any clear purpose. Turnitin generally permits language improvements by AI that preserve the original logic and structure of the text but tends to flag out repeating essentially the same point in many different ways, which is typical of texts generated by AI without being led by the human mind. Turnitin is useful but not infallible --- it makes mistakes, sometimes obvious, sometimes not. It is important that Turnitin openly acknowledges these

limitations by advising that its AI score cannot definitely assess whether plagiarism has happened or not, it merely flags issues for teachers who should apply their understanding and, in the long run, develop educational approaches that align with AI capabilities [45]. Education should be guided by humans, not by generative and detecting algorithms.

Highly advanced algorithms, such as generative AI, can produce a vast number of possible outputs, but this amount is still minuscule compared to the total number of possible text variations. This opens, at least in principle, the possibility of identifying these outputs with a reasonable probability. For example, current generative AIs have a high probability of using certain word patterns that are common in training sets and this commonality can be detected. Yet, the AI generators can be adjusted, or texts generated by AI post-processed, to avoid detection by a particular algorithm or algorithms. Now we have new text generators, whose text cannot be identified by the old detection tools but nothing can stop us from creating new detection tools that can spot these texts. This arms race can continue (and, most likely, will continue) indefinitely. Effectively, we have two AIs --- a generator and a detector --- playing an intransitive game against each other. The relevant theorem [46] states that as long the game is played openly, there cannot be a universal winner in this game, i.e. one can expect that the arms race between generators and detectors will continue indefinitely.

The coming years will bring a large number of generative AI and text processors that can improve (or mask) any text on any topic and another large number of AI-detection tools. Some companies will have open policies and some will try to get a slice of the service market while keeping their algorithms secret. The educators will have to deal with diverse mixtures of human intellect and AI-generated content of various origins. Good education must not become dependent on the arms race between generators and detectors in the crucial question of ensuring the quality of its graduates. The standards of education cannot hinge on acquiring new, most recent detection tools. Instead, reputable educational institutions must establish a framework of educational principles that are vital for maintaining high

standards in the new era of AI. A version of such principles is suggested in the current article.

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