Part 10 / Strand 10

Science Curriculum and Educational Policy

Editors: *Eilish McLoughlin & Odilla Finlayson*

Part 10. Science Curriculum and Educational Policy

Curriculum development. Reform implementation, dissemination and evaluation. International comparison studies such as TIMSS and PISA. Evaluation of schools and institutions. Policy and Practice issues: local, regional, national, or international issues of policy related to science education.

Part 10: INTRODUCTION

Science Curriculum and Educational Policy

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Introduction

The 2015 OECD report on the *Future of Education and Skills Education 2030* challenged governments to future-proof national education systems by raising two key questions – what competencies and skills will be needed in the future? How will these competencies be implemented and assessed? Several studies have shown a disconnect between what educators consider competencies and skills and employers' expectations of 21st Century graduates. Two contributions in this section provide useful insights for framing education policy and developing science curricula against a growing international movement to design and implement STEM curricula in schools. A key challenge for educational systems is to design and use assessment strategies that measure students' competencies and skills. To this end, one of the contributions examines the use of high-stakes examinations, which are a common feature at the end of upper secondary education, in assessing student learning in science.

Tetsuo Isozaki and Takako Isozaki propose that exploring the historical and socio-cultural nature of science and technology education and the relationship between them will provide foundational data that can be used to organise effective collaboration or integration among STEM subjects to develop STEM literacy. Their study investigated the socio-historical nature of science and technology education and compared its origins in European and East Asian countries in the second half of the nineteenth century, with a particular focus on UK and Japan. They report on different approaches to the introduction of science in schools due to the state's education intervention: while British scientists argued the importance of teaching science from the perspectives of the utilitarian and cultural values of science to the intellectual culture of human development, there was a little obstacle to the introduction of science into Japanese schools by the centralised government from the perspective of the utilitarian value of science. They conclude that to facilitate student learning in STEM education, they need to interlink diverse knowledge to solve issues in a social context by learning how to fit what they have learned in each subject into a general STEM scenario.

Radu Bogdan Toma reports that the STEM movement is symbolic of a recurring story about how policymakers promote educational trends that lack scientific support or are grounded on theoretical principles whose soundness is yet to be established. His study reflects on the educational and research practices that are being proposed under the STEM umbrella. He argues that the STEM movement conceals a strong neoliberal ideology aimed at fuelling nations' competitiveness by growing a workforce in these fields. He concludes that "STEM" is widely used in the educational landscape as a slogan to attract funding and economically exploit educational books and materials now rebranded as STEM and marketed as educational innovations. He summarises that the value of the STEM movement is equivocal at best and raises concerns about the tendency to lump different approaches under the same popular acronym.

Damienne Letmon, Odilla E. Finlayson and Eilish McLoughlin present their examination of high-stakes physics and chemistry examinations using Bloom’s revised taxonomy. They report that a common feature of many educational systems is high-stakes examinations, marking the end of upper secondary education. The challenge for these examinations is to pose questions that not only assess students’ content knowledge but also assess students’ learning across cognitive domains. Their study compared the cognitive domains of the high stake-written physics and chemistry 2016 examinations of six countries (England, Ireland, the Netherlands, New South Wales, South Africa and Scotland) using a defined list of action-verbs associated with Bloom’s revised taxonomy. They concluded that the cognitive demand “remember” was assessed to varying extents in all but one of the examination papers. In general, across all Physics and Chemistry examinations, there was a strong emphasis on assessing the cognitive demands of “understand” and “apply” and less emphasis on the domains of “analyse” and “evaluate”. None of the examinations had questions coded for the cognitive skill ‘create’.

These contributions demonstrate the commitment within ESERA to researching curriculum and policy using a range of methodologies and including international and comparative studies. We hope you will enjoy reading the papers and that they provide models for related studies in other European policy areas across Europe and beyond.

THE RELATIONSHIP BETWEEN SCIENCE AND TECHNOLOGY EDUCATION IN THE NINETEENTH CENTURY: A COMPARATIVE HISTORY BETWEEN THE UK AND JAPAN

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While there is abundant literature on science and technology education, few studies have explored their relationship from historical perspectives. Exploring this relationship and the historical nature of each subject will provide information on how to organise science, technology, engineering, and mathematics (STEM) education in contemporary schools. As a case study, we investigated the socio-historical nature of scientific and technical education, comparing its origins in the European countries and East Asian countries in the second half of the nineteenth century, focusing on the UK and Japan, respectively. We found different attitudes towards scientific and technical education in the UK and Japan due to varying socio-historical contexts. In the historical context, we concluded that science educators need to deeply consider the following question from the state's contexts and cultural perspectives: What is STEM literacy for?

Keywords: science and technology education, STEM literacy, culture and education

BACKGROUND AND PURPOSE OF RESEARCH

Extant literature involving government documents on secondary school science and technology (or scientific and technical) education suggests that the two departments should work together for improving science, technology, engineering, and mathematics (STEM) education. However, few studies have explored the historic relationship between science and technology under STEM education, and how such collaboration has worked in the historical context. Exploring the historical and socio-cultural nature of each subject and the relationship between them will provide foundational data that can be used to organise effective collaboration or integration among STEM subjects to develop STEM literacy (Bybee, 2010).

As described in *Nature* (1904), Japan acquired 'European knowledge' (p. 97) at the beginning of its modernisation period in the mid-nineteenth century, and the newly organised government encouraged the introduction of 'scientific technology' (Watanabe, 1976, p. 127) or science and technology without deeply reflecting the historical context of Western culture and religion. Although Japan generally adopted Western ideas, it took a different approach to scientific and technical education. Consequently, there are striking differences in scientific literacy between East Asia (primarily Japan) and the West (*Nature*, 2010) even today.

Although Jenkins (2019) argued that 'reflection on the past is necessarily limited as a guide of the future' (p. 170), comparing different countries' approaches to science and technology education can help to understand the socio-historical contexts and the nature of science and technology to reflect on the effective relationship between the subjects. Therefore, this research aims to recognise the nature of STEM subjects by exploring the historical and socio-cultural relationship among them, primarily between science and technology, to establish a foundation on which STEM literacy can be subsequently developed. As opposed to previous research, this comparison can provide a model for a more precise examination of similar historical and socio-cultural issues in other countries.

RESEARCH METHOD

A professor at Tokyo Higher Normal School, Takahashi (1908) showed that there were three cultural and religious factors of influence to Japanese culture in the period of modernisation, just before 1872, when the modernised school system was established: China, Buddhism, and the West. He argued that China and Buddhism did not contribute much to the development of scientific ideas. However, the influence of the West was very marked. Therefore, the authors employed a comparative historical approach (Briggs, 1972) between the UK (primarily England) and Japan in the second half of the nineteenth century. As British and Japanese historians and economists (e.g., Green,1997, Hobsbawm, 1975, Morishima, 1982) argued, Japan took a different approach to development of education comparing the UK. Isozaki and Pan (2016) described the UK as the 'science export country,' while Japan was the 'non-Axial civilization' and the 'science import country.' British Royal Commissions, such as the Devonshire Commission (1875) in the nineteenth century revealed that British education, especially scientific, technical, and engineering education lagged behind state-supported education in comparison to continental countries, such as France and Germany. The state-intervention in education led to varying ways of approaching science and technology teaching.

LITERATURE REVIEW

Extensive literature exists on the history of scientific and technical education in the UK; for example, Turner (1927), Cardwell (1972), Layton (1973), and Jenkins (2019) wrote about science education; and Argles (1964) and McCulloch, Jenkins, and Layton (1985) on scientific and technical education. Sociologists of education, such as Green (1997) and Young (1986), also discussed the historical evolution of scientific and technical education. Some researchers have compared the UK's approach with that of other European countries, such as France and Germany, but there have been few similar comparisons with Japan. There is considerable literature on the history of science education in Japan (*rika* in Japanese: Ogawa, 2015). With a few exceptions, such as Isozaki (2014, 2017), almost all literature is in Japanese, without any reference to the relation between scientific and technical education. However, the existing research can provide several analysis points for our current research, such as the relation between the nation state/country and approach to education.

THE BACKGROUND IN THE NINETEENTH CENTURY

Although the UK was still enjoying the first success of the Industrial Revolution and its economic supremacy, Hobsbawm (1975) highlighted that one significant consequence of a science-based industry was that the educational system, especially primary/elementary and higher education, became increasingly crucial for industrial development. The continental countries recognised that scientific and technical education was regarded as an essential vehicle of economic growth, and industrialisation occurred under the initiative and tutelage of the state. For example, France had the *École Polytechnique* and *grandes écoles* and Germany had organised *Technische Hochschule* at that time.

However, in the case of the UK, some economists (e.g., Hobsbawm, 1975) and historians (e.g. Ashby, 1963; Green, 1997; Winer, 1981) argued that despite the economic advantages of the early success of the Industrial Revolution, the British backwardness in scientific and technical education in the nineteenth century was explained as the so-called ‘cultural critique’ (Green, 1997, p. 56) which focused on the anti-industrial and anti-utilitarian culture, and the doctrine of *laissez-faire*. As Ashby (1963) and Green (1997) stated, public and grammar schools remained classical culture, and until the last quarter of the nineteenth century, universities did not contribute towards scientific and technical needs.

Japan had the foresight to address the urgent issue of modernisation to avoid being a victim of the Western capitalism comparing such as other Asian countries, and was able to exercise nation state power without fierce resistance from public opinion. Thus, Japan’s leaders were convinced that ‘the only way to catch up with the economic superpower Britain was through education’ (Stephens, 1991, p. 26); other fields, such as finance, foreign affair, and military, were urgently and strongly centralised. Consequently, as Hobsbawm (1975) stated, Japan was the only country of all the non-European countries that succeeded in meeting and beating the West and never applied *laissez-faire*. Economist Morishima (1982) argued that the newly organised Japanese government successfully achieved ‘take-off’ in the Japanese economy, which was a different spirit from English capitalism: ‘economy combining Japanese soul and Western technology’ (p. 87). As a way to establish the modernised society in Japan, the government had employed *oyatoi-gaikokujin*, who were foreign advisors and teachers of various fields such as education, science, and engineering with high salaries. For example, based on the advice of British engineer Edmund Morel to facilitate industrial development, the Japanese government established the Ministry of Public Works in 1870 and the Institution of Engineering in 1871 (later changed to the Imperial College of Engineering in 1877, and then Faculty of Engineering, the Imperial University, in 1886). Relatively more British scientists and engineers who were teachers of the Imperial College of Engineering, such as Henry Dyer, William E. Ayrton, and John Milne, were recruited as *oyatoi-gaikokujin* than in any other western country. Consequently, Watanabe (1976) argued that Japan introduced ‘scientific technology’ (p. 123) or science and technology, not only pure science.

THE CONDITION OF SCIENTIFIC AND TECHNICAL EDUCATION OF SECONDARY SCHOOLS IN THE UK AND JAPAN

Green (1997) argued that throughout the nineteenth century, British scientific and technical education was notably backward in comparison to that of other countries in Europe. In the UK, several Royal Commissions were organised in the second half of this period, such as the Public Schools Commission (Clarendon commission: 1861–1864), the Scientific Instruction and the Advancement of Science (Devonshire commission: 1871–1875), the Royal Commission on

Technical Instruction (Samuelson commission: 1882–1884), and the Royal Commission on Secondary Schools (Bryce commission: 1895). These Royal Commissions revealed that inadequate scientific education was taking place in the public and grammar schools. They recommended the importance of teaching scientific and technical education. The Devonshire Commission (1875, p. 4) highlighted the chief reasons for such schools to omit teaching science (1) absence of funds; (2) uncertainty about the educational value of science; and (3) difficulty of finding time for a new subject in an already overcrowded curriculum. Particularly, the second reason was crucial for the introduction of science teaching in schools. Therefore, Victorian scientists, such as Thomas H. Huxley (1895), witnesses of the Devonshire commission (1875), and members of the British Association for the Advancement of Science (BAAS) (1868), noted the importance of teaching science as an essential part of 'Liberal Education of a great branch of Intellectual Culture' (Devonshire commission, 1875, p. 10) from utilitarian and cultural values of science. This meant that advocates of science education took care to distinguish it from technical education. Curtis (1965) indicated that even if the Clarendon Commission had recommended that science should be placed into public schools' curricula, the essential idea of the commissioners who were impressed by the German Gymnasium was that studies of the classics should remain as the core of the curriculum in public schools. Despite these efforts, and political and public opinion to support science (*Nature*, 1885), its 'progress was slow' (Cotgrove, 1958, p. 29; Jenkins, 2019, p. 75). To be worth adding to the school curriculum of the public and grammar schools, science had to be 'pure and academic' (e.g., McCulloch, Jenkins, & Layton, 1985; Jenkins, 2019). Although the Bryce Commission (1895) recognised technical education as part of the newly defined 'secondary education', it was of 'perennially low status, conservatively rooted in workshop practice and hostile to theoretical knowledge' (Green, 1997, p. 72).

In contrast to the UK, there was little struggle to organise science education (*rika*) in Japan, as science had been established as an essential component of Japanese secondary school curricula since its institutionalisation in the second half of the nineteenth century. The Japanese had introduced Western science due to its utilitarian value in schools through textbooks as 'teachable science' (Knight, 1992). For example, Roscoe's *Science primers: Chemistry* (1872), which aimed to understand science principles through a series of chemical experiments, and 'by bringing it into immediate contact with Nature herself' (Roscoe, 1872, preface), was quickly and completely translated into Japanese in 1874 to be used as an elementary school textbook; however, in many cases, it was used for 'reading' due to a lack of suitable teachers with sufficient knowledge of Western science at that time. Secondary school's conditions were similar to the case of elementary school. Although the curriculum tended to favour pure and academic science, as in the UK, it sometimes referred to science in the context and relevance to daily life in Japan. Since the modernisation in the mid-nineteenth century, Japanese science educators have constantly observed and been influenced by the trends of science education in the West. However, technical education in Japan, as a part of secondary vocational education, had been institutionalised since the 1880s. While vocational secondary school curricula essentially depended on the school's policies and enhanced workshops, physics and chemistry were included in the basic study for vocational education. Therefore, unlike in the UK, science and technology education were separated, and there was no debate about the definition of technical education as a part of vocational education or its distinction from science education in secondary education. When Dairoku Kikuchi, who graduated from the University of Cambridge, translated Russell’s book (1869) *Systematic technical education for the English people* into Japanese (Kikuchi, 1884), he used the term ‘*shokugyou kyouiku*’ in Japanese which means ‘vocational education’ as the translated term ‘technical education.’ This means that in Japan, technical education was placed as an essential part of vocational education, not general education that intended to go to higher education level.

SCIENTIFIC AND TECHNICAL EDUCATION AND ENGINEERING IN THE UK AND JAPAN

Russell (1869), Arnold (1892), Huxley (1895), and the Royal Commissions showed that compared to continental countries, such as France and Germany, the UK (especially England) was notably backward in most areas of scientific and technical education throughout the nineteenth century. However, as Cotgrove (1957) stated that distinguishing between science and technical education in the nineteenth century in the UK was difficult, Huxley (1895) used two terms ‘technical’ and ‘scientific’ education without a clear definition in his lectures. The UK, especially England, lacked the connection between science theories and their application to industry. Ayrton (Samuelson Commission, 1884), who was a distinguished teacher at the Imperial College of Engineering in Tokyo, as a witness to the Samuelson Commission noted that there are two kinds of technical education: of a master of works and of a workman (Samuelson Commission, 1884, p. 115); he explained about the Imperial Colleges as all the branches of technical education were brought under ‘engineering’. Referring to William Thomson’s (Lord Kelvin) instruction at the University of Glasgow and his experience at the Imperial College, Ayrton pointed out that ‘[t]echnical education is the application of science to industry’ (Samuelson Commission, 1884, p. 118). This definition primarily targeted the higher education level which is similar to ‘engineering education.’ For him, engineering education included scientific theories and their application to industry; whereas, the technical education of a workman meant the workshop training that gave ‘accuracy of eye and dexterity of hand’ (Samuelson Commission, 1884, p. 118) without scientific theories. The pride of anti-industrialism in education created an ignorance of manual work, applied science and trade instruction (Vlaeminke, 1990, p. 73).

In Japan, the Ministry of Public Works invited Dyer as the principal from Glasgow to stablish the Imperial College of Engineering in Tokyo. Many of the staff involving a principal at the college were British, such as Ayrton and Perry, who were later professors at the Finsbury Technical College in London. Dyer (1904) attempted to adopt the unified system that combined two systems for educating engineers in the continental countries, such as France and Germany, with the British system in the college. Therefore, the programme provided ‘a highly scientific training, combined with actual practical experience in engineering workshops’ to students (*Nature*, 1877, p. 44), and the course of the college included three courses: (1) general and scientific, (2) technical, and (3) practical (Dyer, 1904, p. 5). The method of combining theory and practice in the training of engineers was called the 'sandwich' (Dyer, 1904, p. 427) system. Additionally, Dyer (1879) recognised the importance of foreign language and Japanese literature as well as scientific studies as a part of liberal education in college and engineering studies. It is noteworthy to state the following: (1) Ayrton's Japanese laboratory was highly praised, and his colleague Perry reported that 'Maxwell jestingly said that the electrical centre of gravity had shifted toward Japan (from Glasgow, London, and Berlin [the authors added])' (*Nature*, 1908, p. 74), and (2) Dyer (1904) titled one of his books: *Japan as the Britain of the East*, and stated that 'the chief lesson to be learned from Japan is the need for a truly national spirit for the accomplishment of great ends' (p. 427). Brock (1980) concluded that the shared experience of teaching science and engineering of Ayrton and Perry at the Imperial College of Engineering in Japan was a necessary factor in the success of the Finsbury Technical College in London, and highlighted that this is a typical case of 'the experience of reverse transculturation' (p. 239). Ironically, under the leadership of British scientists and engineers, engineering in higher education was organised earlier in Japan than in the UK, specifically England.

Based on the suggestion by the German *oyatoi-gaikokujin*, Gottfried Wagener, and Japanese politicians, the Japanese Ministry of Education established the Tokyo Vocational School. The school provided technical and industrial science education for becoming vocational school teachers and senior management engineers in 1881 (Tokyo Institute of Technology, 1940). In 1899, the vocational school order for secondary school education was promulgated, and vocational schools were categorised into five types: technical schools, agricultural schools, commercial schools, merchant marine schools, and vocational supplement schools. Every old Imperial University established before WWII in Japan had a Faculty of Engineering (or Faculty of Science and Engineering). Dyer's engineering education became the origin of engineering education in Japan. Due to the timely organisation of engineering education in higher and technical education during secondary education, Japan succeeded in becoming industrially developed similar to the Western countries. However, the connection between engineering education and technical education in the nineteenth century in Japan was feeble.

THE APPROACHES TO SCIENTIFIC AND TECHNICAL EDUCATION OF SECONDARY SCHOOLS IN THE UK AND JAPAN

Why did the approach to the organisation of scientific and technical education vary between the UK and Japan in the second half of the nineteenth century? Extant literature notes that educational intervention in the UK was limited due to the doctrine of *laissez-faire* (e.g., Layton, 1973; Green, 1997; Isozaki & Pan, 2016). There were other reasons such as a lack of suitable teachers (e.g., Turner, 1927; Jenkins, 2019), anti-science and anti-technology counterculture (Young, 1986), and an anti-industrial and anti-utilitarian culture (Vlaeminke, 1990, Green, 1997). These 'cultural critique(s)' (Green, 1997, p. 56) can be attributed to the 'English gentleman' (Jenkins, 2019, p. 61) effects. Additionally, Green (1997) indicated the failure 'in the response of new industrial and bourgeois classes' (p. 58). Under these circumstances, Victorian scientists, Royal Commissions, and BAAS advocated the importance of utilitarian and cultural values of science to intellectual culture. They argued that human development should require the inherent value of science in addition to the value of classics. Thus, the purpose of science education, in other words, the significance and value of learning science was firmly debated. As a result of Victorian scientists' and politicians' efforts, science education was gradually placed in the public and grammar schools. However, science education intended to be pure and academic, such as mathematics education, rather than technical education, and lost its relevance to everyday life and industry at the secondary education level.

In contrast, when Japan's modernised society was newly established in the second half of the nineteenth century, Japan's state intervention in education was much stronger than that of the UK (Isozaki, 2014; Isozaki, & Pan, 2016). Compared with the UK, Japanese leaders had fewer anti-cultural feelings towards science and technology, and the impact of the scientific technology of Western civilisation characterised as 'steam and electricity' (Watanabe, 1976, p. 123) was extremely significant for both the leaders and the people. Therefore, the utilitarian value of science was enhanced by its introduction in school. Although Japan did not have well-educated teachers in Western science and technology at the beginning of the modernisation period, the government invited foreign advisors and teachers from Western countries and sent students to study science and other academic fields in the West. In addition, Western science books were quickly translated into Japanese for school use. Consequently, with few obstacles, the Japanese politicians and educators successfully recontextualised Western science for teaching in Japan (Isozaki, 2014). The school subject science (later *rika*) was firmly placed in school curricula from elementary throughout higher education levels from the beginning of modernisation in the mid-nineteenth century. In contrast to the UK, however, even though teachers were keen to know how to teach science, there was little opportunity to deeply debate the purpose of science education. Technical education at the secondary school level was placed as a part of vocational education and was distinct from science. The purposes of engineering at higher education and technical education during secondary school education were naturally different, and there was no connection between them.

We can observe the different approaches to the introduction of science in schools due to the state's education intervention: while British scientists argued the importance of teaching science from the perspectives of the utilitarian and cultural values of science to the intellectual culture of human development, there was little obstacle to the introduction of science into Japanese schools by the centralised government from the perspective of the utilitarian value of science. Therefore, Japanese science teachers were keen to understand how to teach science introduced by the West in the classroom.

DISCUSSION AND CONCLUSION

The attitudes toward scientific and technical education were different in the UK and Japan due to socio-historical contexts in the nineteenth century. While British scientists and educators struggled to establish science in schools, they engaged in reflective thinking about the purpose and methods of science education, considering the following questions: *What is science for?*

Moreover*, why and how should science be taught in schools?* Additionally, *what contents of science should be taught?* For example, BAAS (1868) sought to acquire scientific information and promote scientific training; further, the Devonshire Commission (1875) argued that science could contribute to 'the training of [one's] intellectual power' and supply one with 'valuable information' (p. 6). Huxley (1895) proposed the scope and sequence of teaching contents of science and wrote many science books, such as *Introductory* (1880), which was a series of science primers edited by Huxley, Roscoe, and Balfour Stewart, and *Physiography* (1887) focused on observation and object lessons. Henry E. Armstrong (1903), a colleague of Ayrton and Perry at the Finsbury Technical College, criticised Huxley's book (1887)*: Physiography* as 'the book to be avoided' (Armstrong, 1903, p. 86), and proposed the heuristic method in laboratory in science teaching. Consequently, the Victorian scientists argued the importance of teaching science from perspectives of utilitarian and cultural values of science, and then proposed the teaching contents with scope and sequence, and methods of science teaching.

In contrast, leaders of the new Japanese government introduced Western science into schools based on the utilitarian values of science. They encouraged the integration of Western scientific technology and Japanese soul or spirits as Dyer (1904) and Morishima (1982) argued. Japan imported the established Western framework of science education without its background, such as philosophy. Therefore, when a new scientific subject known as '*rika*' was established in the elementary school curriculum in 1886 by the government, there was a surprise about '*rika*' and there was a discussion about 'what *rika* is' among teachers (Takahashi, 1908). The central government always stated the purpose of science education (*rika*) through orders. This circumstance led Japanese science educators to miss the opportunity to deeply discuss the following questions: *What is science for?* Moreover*, why should science be taught in schools?* They did not deeply consider the nature of Western science and technology and their educational and social functions at that time. Consequently, while British science educators focused on reflecting on the abovementioned questions when they argued the values of science in education and proposed scientific methods, Japanese science educators focused on considering *how* science (*rika*) should be taught in classrooms, because Japanese science educators took for granted that the purpose of science education (*rika*) was given through every revision of the orders issued by the central government. Although 'science' in schools was introduced by textbooks as teachable, there was a lack of suitable teachers to teach and be familiar with Western science at that time. Consequently, they introduced the methods of science teaching proposed and practiced in the West, such as object lessons (Huxley, 1887), and the development-principle education theory by James Johonnot (1896), primarily in elementary education. Some progressive science teachers gradually allowed secondary school students to conduct experiments around the twentieth century, just before and after introducing the heuristic method into Japan from the UK (Kametaka, 1904).

Scientific and technical education were difficult to distinguish, and the relation between technical and engineering education was also unclear in the UK in the nineteenth century. Contrastingly, technical education was firmly placed as a part of vocational education in secondary education, and there was a clear distinction between science education (*rika*) and technical education in Japan. Although science education (*rika*) included content relevant to daily life, it was never technical education. In Japan, engineering education was organised at the higher education level by strong initiatives of government under the leadership of British scientists and engineers, as opposed to the case of the UK.

These facts in the case of the second half of the nineteenth century in the UK and Japan exemplify that every school subject in each country has its own historical and socio-cultural background, which features the nature of the subject that is unique from the other subjects in contemporary schools. The historical and socio-cultural relationship between mathematics and the other three subjects has not been discussed, because this relationship was not as problematic as the relationship between scientific and technical education both in the UK and Japan in the nineteenth century. Investigating this relationship is a separate issue that remains to be studied; the present case study will be adapted within the continental countries, such as the UK and France, or Germany, and other Asian countries.

In STEM education, students may need to inter-link diverse knowledge to solve issues in a social context by learning how to fit what they have learned in each subject into a general STEM scenario. When we consider the following question: '*What is STEM literacy for?'* in the historical context, we must recognise the nature of each STEM subject and examine the question from the state's contexts and socio-cultural perspectives. Therefore, as Wong and Dillon (2019) state, from historical perspectives, a 'collaboration' rather than an 'integration' represents the nature of the relationship between the subjects of STEM education in Japan. Consequently, we consider how to collaborate between STEM subjects based on considering the nature of each STEM subject for effectively developing STEM literacy.

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STEM; OR THE MODERN PROMETHEUS OF SCIENCE EDUCATION

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There is a sense of déjà vu in the STEM movement, reminiscent of the story about how didactic approaches based on theoretical ideas whose soundness has yet to be demonstrated are strongly advocated. Despite the acronym's popularity, many aspects of the STEM discourse demand scrutiny. In this proposal, I reflect on the educational and research practices that are being proposed under the STEM umbrella. After contextualizing the STEM acronym in its historical contexts, I argue that the STEM movement conceals a strong neoliberal ideology aimed at fuelling nations' competitiveness by growing a workforce in these fields. As a result, I question the novelty of many STEM-related proposals especially insofar as they resemble long-standing science education efforts. This leads me to the conclusion that "STEM" is widely used in the educational landscape as a slogan to attract funding and economically exploit educational books and materials now rebranded as STEM and marketed as educational innovations. As a result, the value of the STEM movement is equivocal at best and raises concerns about the tendency to lump different approaches under the same popular acronym.

Keywords: integrated curricula, STEM education, science and mathematics

INTRODUCTION

The STEM movement is symbolic of a recurring story about how policymakers promote educational trends that lack scientific support or are grounded on theoretical principles whose soundness is yet to be established. In this sense, STEM has evolved into a major slogan that has gradually monopolized the international discourse on science education improvement. Despite the acronym's popularity, many aspects of the STEM debate require close examination. Against this background, I reflect on (i) its origins and the ideology that underpins such a movement; (ii) how it is conceptualized in the science education literature; (iii) and how it is used in the educational landscape.

ORIGINS OF THE STEM ACRONYM

The acronym STEM was coined in the 1990s by the National Science Foundation (NSF) as a "strategic decision made by scientists, technologists, engineers, and mathematicians to combine forces and create a stronger political voice" (STEM Task Force Report, 2014, p. 9). This acronym drew the attention of the educational community following the publication of the *Rising Above the Gathering Storm* reports (NAS et al., 2007, 2010), which argued that the United States (U.S.) advantages in terms of innovation and technological progress have begun to diminish in the last decade. The second edition of such a report painted "(…) a daunting outlook for America if it were to continue on the perilous path it has been following in recent decades concerning sustained competitiveness" (NAS et al., 2010, p. 2).

In short, while other nations made significant progress in the STEM disciplines, the U.S. ability to compete effectively deteriorated, which calls for greater emphasis on the development of educational programs aimed at the promotion and retention of talent in Science, Technology, Engineering, and Mathematics disciplines (Bybee, 2018). As a result, STEM has quickly become a policy slogan aimed at boosting international competitiveness and is being used to refer to initiatives that are in tandem with growing a workforce in these disciplines (Toma & García-Carmona, 2021; Weinstein et al., 2016).

Consequently, behind this acronym hides a 'Trojan horse' that projects false prosperity, welfare, and status but, in essence, hides a pronounced capitalist ideology (Bencze et al., 2018) and represents a deficient educational model that does not advance in the resolution of the problems faced by contemporary science education (Zeidler, 2016). Hence, STEM is an ideological positioning of science education (Carter, 2017) that seeks to align school science curricula in a direction “that reinforces and legitimizes a neoliberal hegemony of global competition and capitalist expansionism” (Weinstein et al., 2016, p. 201).

In this sense, STEM is used to proclaim the need for another Sputnik moment to address the decline of U.S. competitiveness (Bybee, 2013). The STEM movement looks to be the modern-day Sputnik, aimed at recharging US competitiveness against China in the same way as the 1957 satellite launch triggered the implementation of scientific education reforms to reclaim technological advancements lost to the Soviet rival. Thus, what appears to be an essential condition for U.S. development materializes in an ideological positioning of science education, which, framed under the STEM umbrella, stands as a vehicle to serve the goals of neoliberal political agendas (Carter, 2017).

CONCEPTUALIZATIONS OF STEM

To access financial grants devoted to projects promoting such a discourse, the STEM acronym became widely present in the educational landscape worldwide and rapidly acquired a wide spectrum of meanings and conceptualizations. Indeed, while the acronym started as a political discourse for national and state policies, it quickly began to be coined by educators and researchers as an educational movement with the ambitious goal of increasing the number of students pursuing STEM-related careers (Tanenbaum, 2016).

As a result, STEM is being conceptualized from an educational standpoint through a broad continuum of diverse and sometimes contradictory educational initiatives. Existing definitions range from a greater emphasis on STEM coursework to calls for the adoption of integrated curricula (Toma & García-Carmona, 2021). This notion of STEM, often known as integrated STEM, attempts to closely resemble how STEM knowledge is generated and applied in real life. It is suggested that "STEM content should not be taught in isolation, but rather in a way that reflects how STEM knowledge is used outside of school; this knowledge is further contextualized or driven by some problem or issue” (Dare et al., 2018, p. 4).

However, most definitions of integrative STEM relate to the integration of two or more disciplines, eerily similar to previous attempts in the 1980s and 1990s that focused on the integration of science and mathematics (for a review, see Toma & García-Carmona, 2021). For example, Sanders (2009) defined it as a teaching approach that explores the connections among any two or more of the STEM subject areas, and/or between a STEM subject and any other school subjects. Similarly, Moore et al. (2014) referred to STEM education as "(…) an effort to combine *some* or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit or lesson that is based on connections between the subjects and real-world problems" (p. 38, emphasis added). Kelley and Knowles (2016) defined integrated STEM as "(…) the approach to teaching the STEM content of *two or more* STEM domains, bound by STEM practices within an authentic context for the purpose of connecting these subjects to enhance student learning" (p. 3, emphasis added).

There are significant educational antecedents for such curricular integration, including initiatives championed by the Science and Mathematics integration (S&M) and the Science-Technology-Society (STS) movements (Aikenhead, 2002; Pang & Good, 2000). Hence, one wonders whether STEM, following such a definition, should be considered a new approach at all and if it adds any value to science education. Likewise, the lack of a theoretical and pedagogical framework guiding the didactic transposition of such integration into classroom practice has led to using this acronym in empirical studies addressing solely one discipline in isolation, thus being inconsistent with the promoted discourse of curricula integration (for reviews, see Martín-Páez et al., 2019; Toma & García-Carmona, 2021).

HOW IS THE STEM ACRONYM USED

Given the ambiguity inherent in STEM, it is unsurprising that many experts are coining new acronyms such as STEAM (STEM + ARTS), iSTEM (imagination and STEM), or STREAM, which refers to STEAM + robotics or STEAM + reading (for a full discussion, see Toma & Garca-Carmona, 2021). This *STEMification* of the science education scene is therefore not surprising, given the substantial investments in research and educational projects framed around this acronym (Anderson, 2020). When assessing educational materials, the use of STEM as a convenient buzzword becomes even more obvious (Figure 1). A growing number of educational materials are being promoted using the STEM acronym. An inspection of these products reveals that they are remarkably similar to products that have been promoted for decades but are now rebranded as innovative STEM resources.

On the other hand, there is a plethora of research articles conveniently including the STEM acronym in their titles (Figure 2). Yet, much of such research addresses only one discipline (Martín-Páez et al., 2019). Amidst this situation, several critical voices complain that STEM is being promoted at the expense of an operational definition. In an attempt to disentangle the meaning of STEM, Akerson et al. (2018) concluded that STEM is a "(…) socially constructed label that is in response to economic and global pressure" (p. 5) and that the advent of the STEM movement is reducing attention to other important aspects of science education, such as the teaching of nature of science.

CONCLUDING REMARKS

In this proposal, I discuss key features of the STEM movement. In this sense, I situated STEM as a political slogan that conceives science education as a tool for achieving capitalist goals.

Next, I highlighted that existing definition contradicts the STEM discourse calling for the integration of four disciplines, and that such conceptualizations resemble integrated curricula approaches that have been promoted for over four decades. Finally, I draw attention to the commercial usage of this acronym in marketing products, accessing funding, or bringing attention to scientific publications.

Figure 1. Example of material marketed under the acronym STEM or STEAM.

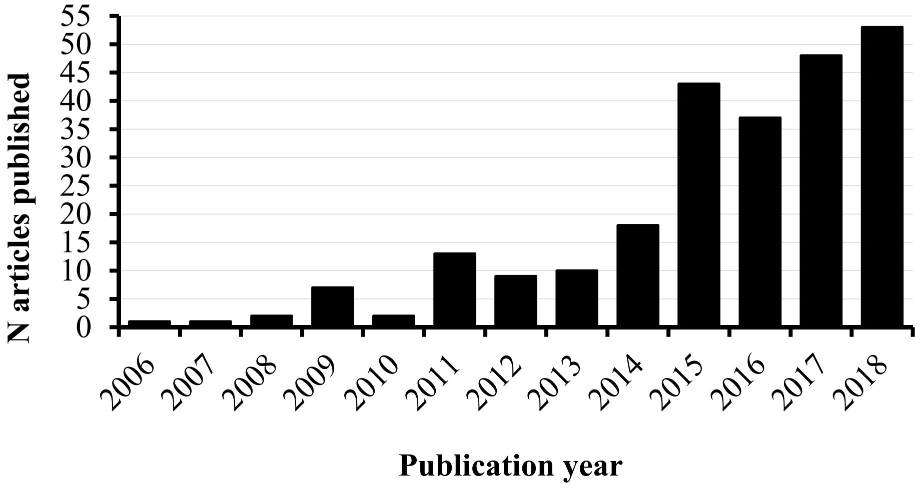

Figure 2. Articles indexed in the Web of Science database that use the term "STEM education" in their titles.

STEM education is therefore inevitably evocative of Frankenstein's monster, in that it is devised from an accumulation of outdated strategies reimagined in such a manner as to represent a new creature that is presented to the educational community as an innovative approach. Thus, the STEM acronym (or perhaps, better referred to as *FrankenSTEM*) is a political movement that translates into an educational model of questionable innovation that lacks research-based support. Likewise, its disproportionate use raises critical concerns about the tendency to lump educational efforts under a popular heading to attract funding, as well as for the commercial exploitation of books and educational materials now promoted as STEM.

In this context, I wonder if educators will recall Mary Shelley's words in *Frankenstein, or The Modern Prometheus*, as they reflect on STEM in the coming years: "How to describe my emotions at this catastrophe, or how to delineate the wretch whom with such infinite pains and care I had endeavored to form?"

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EXAMINING HIGH STAKES PHYSICS AND CHEMISTY EXAMINATIONS USING BLOOM'S REVISED TAXONOMY

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A common feature of many educational systems are high stakes examinations which mark the end of upper secondary education. The challenge for these examinations is to pose questions which not only assess students' content knowledge but also assess student's cognitive skills. This study compares the cognitive skill levels of the high stake written physics and chemistry examinations of six countries (England, Ireland, the Netherlands, New South Wales, South Africa and Scotland) using a defined list of action-verbs associated with Bloom's revised taxonomy. The examination year of 2016 was selected as the syllabi and examination system of these six countries had not changed in the two previous years with similar topics being examined. The analysis of higher order cognitive levels showed that across the physics examinations there was a greater focus on assessing the cognitive skill of 'apply' from 70% (Netherlands) to 23% (New South Wales) with a smaller percentage of questions assessing 'analyse' and 'evaluate'. Across the chemistry examinations between 83% and 99% of the marks were for questions assessing 'remember', 'understand' and 'apply' with very few questions assessing 'evaluate'. The 'evaluate' skill level was less than 16% in physics and less than 7% in chemistry. None of the examinations had questions which coded for the cognitive skill 'create'.

Keywords: Cognitive skills, Physics and Chemistry Examination, Blooms Revised Taxonomy

INTRODUCTION

The high-stakes public examinations which mark the end of upper secondary education have been a common feature of most education systems. These high-stake assessments, irrespective of the form of such assessments, are based on a specifically drawn-up programme or syllabi mandated or approved by the relevant educational bodies. Dufaux (2012) described such high-stakes examinations as 'assessments for qualification and certification' as they provided access to third level education, be it academic or vocational as well as direct entry to the workforce (Dufaux, 2012; Kellaghan, 1996).

In 2002, Bloom's revised taxonomy was presented as a two-dimentional one comprising of a knowledge component and a cognitive component. At the core of this revised taxonomy was the use of action-verbs associated with each cognitive level. The original first category of knowledge was renamed ***remember.*** The other five categories were renamed with action-verb equivalents of ***understand, apply, analyse, evaluate*** and ***create*** (Anderson, 2005; Krathwohl, 2002; Krathwohl & Anderson, 2010)**.** For the past 20 years this revised taxonomy has been used to assess the cognitive content of high-stakes examinations as well as alignment of these examinations with the curriculum. ((Edwards, 2010; Liu et al., 2009; Motlhabane, 2017; Nurlailiyah et al., 2019; Prashant Thote & Gowri S, 2020; Tikkanen & Aksela, 2012; Tsaparlis

& Zoller, 2003). These studies prompted the two research questions addressed in this paper i.e.

- *How do the cognitive skill levels of high-stakes written physics examinations compare across countries?*
- *How do the cognitive skill levels of high-stakes written chemistry examinations compare across countries?*

To address these questions a cross-national comparison of the examination quesions was carried out using the cognitive dimensions of Bloom's revised taxonomy with the associated action-verbs as the analytic tool of choice (Lee et al., 2017).

METHODOLOGY

Selection of countries for the study

Physics and Chemistry high-stake examinations were selected based on the following criteria:

- Separate examinations for physics and chemistry.
- Comparable topics and question-styles on examination papers.
- Written state-wide standardised examination based on the programme as drawn up by the relevant education authorities.
- Similar adminstration conditions for students sitting the examinations.
- Relevant programme was implemented for at least the previous two years (to ensure syllabi was embedded in the education system).

Using the above criteria, the following public examinations for 2016 from six countries were selected for analysis (Table 1).

Table 1. Countries and relevant examinations selected.

England	A-levels
Ireland	Leaving Certificate Examination
The Netherlands	HAVO (***H****oger* ***A****lgemeen* ***V****oortgezet* ***O****nderwijs)*
New South Wales	Higher School Certificate
Scotland	Highers
South Africa	National Senior Certificate

Coding of the examination papers using revised Bloom's taxonomy

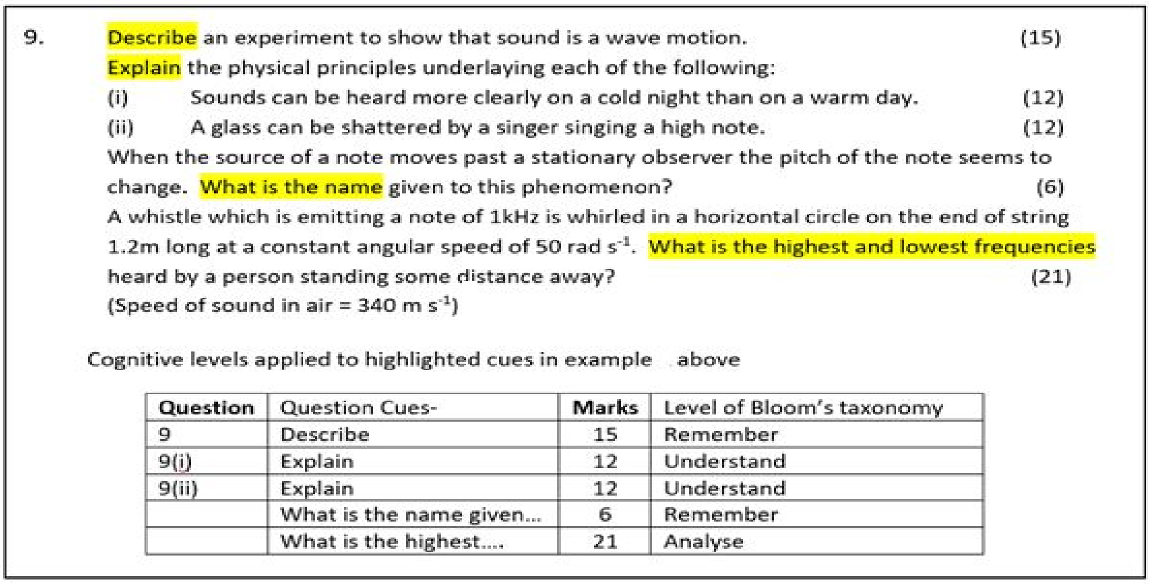
Prior to coding the examination papers, a list of action-verbs was compiled from two independent studies, namely Newton et al (2020) and Stanny (2016). This list comprised of 30 action-verbs per cognitive level. Using such a predefined list reduced the subjective bias in coding the questions. However this subjectivity was tested when action-verbs are registered in more than one cognitive level (Pugh & Gates, 2021). Having identified these action-verbs, a search of the frequency of their occurance in the examination papers was carried out which indicated just eight such verbs (Table 2). Using Krathwohl's definition of each of the levels a supplementry list was drawn up of these action-verbs to include further meaning of the verbs.

Table 2. Supplementry list of eight action-verbs common to cognitive levels (Krathwohl, 2002).

Remember	Understand	Apply	Analyse	Evaluate	Create
		Calculate (mathematical calculations)	Calculate (organising)		
Describe (recalling)	Describe (explaining)			Describe (judgment using criteria)	
	Explain (meaning of terms)	Explain (a procedure)		Explain (judgments using criteria)	Explain (generating original view)
	Identify(denoting)	Identify (procedure)			
	Illustrate (meaning)	Illustrate (a procedure)			
	Predict (infer)	Predict (results of procedure)			
	Show (meaning)	Show (procedure)			
		Write (procedure /formulae)			Write (generating original views)

Determining the cognitive skill levels across the questions

The following coding process was adopted. Action verbs in each question part were idenified and high-lighted. Using the Stanney-Newton compiled list of action verbs each quesiton part was coded to one of the six coginitve levels of Bloom's revised taxonomy. An example of this process is shown in Figure 1.



9. Describe an experiment to show that sound is a wave motion. (15)

Explain the physical principles underlaying each of the following:

(i) Sounds can be heard more clearly on a cold night than on a warm day. (12)

(ii) A glass can be shattered by a singer singing a high note. (12)

When the source of a note moves past a stationary observer the pitch of the note seems to change. What is the name given to this phenomenon? (6)

A whistle which is emitting a note of 1kHz is whirled in a horizontal circle on the end of string 1.2m long at a constant angular speed of 50 rad s^{-1}. What is the highest and lowest frequencies heard by a person standing some distance away? (21)

(Speed of sound in air = 340 m s^{-1})

Cognitive levels applied to highlighted cues in example above

Question	Question Cues-	Marks	Level of Bloom's taxonomy
9	Describe	15	Remember
9(i)	Explain	12	Understand
9(ii)	Explain	12	Understand
	What is the name given…	6	Remember
	What is the highest….	21	Analyse

Figure 1. Example of coding process adopted.

For example, the action verb 'describe' is coded as the cognitive level *remember* (Figure 1) and is the mostly commonly used action verb that required students to recall knowledge. Similarly, the action verb 'explain' was widely used to probe student *understanding* (Table 2).

The inset table in Figure 1 depicts the allocation of marks for the coded question parts. In this example question, which a total of 66 marks available, 21 marks were coded for *remember*, 24 marks for *understand* and 21 for *analyse*. This process was applied across all question parts for each of the six examination papers in physics and in chemistry. The overall proportion of questions parts, which were coded at each of the six cognitive levels, was calculated as a percentage of the total marks available in the examination paper.

FINDINGS

The analysis of these examinations using action verbs associated with Bloom's Revised Taxonomy highlighted the differences in the cognitive skill levels of high-stakes physics and chemistry examinations across these six countries. All six physics and chemistry examinations had questions based on combinations of single-answer questions, short answer questions, context-based questions to include sketch/graph/diagram, computational questions and short essay style questions. Apart from Ireland, students in the other countries had to answer all the questions. Irish students could choose any eight questions of the eleven available on the examination papers to answer.

Table 3 sets out the percentage distribution of each cognitive level for the six physics examinations. Except for Ireland and New South Wales, there was less emphasis on marks being assigned to the lower cognitive skills of *remember* and *understand* with percentage distributions for *remember* ranging between 0% (the Netherlands) and 18% (South Africa)) and for *understand* between 8% (the Netherlands) and 26% (England). In Ireland, 37% of the question parts coded as *remember*, while in New South Wales, 37% of the questions marks coded as *understand.* The majority of question-parts which coded for the cognitive skill *apply* used the action-verb ‘calculate’ with a percentage distritution between 23% (New South Wales) and 70% (the Netherlands). The percentage distribution of questions coding for *analyse* ranged from 1% (Scotland) to 18% (New South Wales). Scotland allocated 15% of the marks to question-parts coding for *evaluate.* None of the countries had questions coding for *create* cognitive skill.

Table 3. Percentage distribution of marks per cognitive skill levels across the physics examinations.

Exam in	***Remember***	***Understand***	***Apply***	***Analyse***	***Evaluate***	***Create***
England	9%	26%	42%	16%	7%	0%
Ireland	**37%**	23%	36%	2%	1%	0%
the Netherlands	0%	8%	**70%**	9%	14%	0%
New South Wales	13%	**37%**	23%	**18%**	11%	0%
Scotland	8%	15%	60%	1%	**15%**	0%
South Africa	18%	10%	**65%**	7%	0%	0%

The percentage distribution for each cognitive level for the six examinations in chemistry is set out in Table 4. Across the six examinations, the percentage distribution of marks assigned to the cognitive levels of *remember* ranged from 10% (New South Wales) to 38% (Ireland). The percentage distribution of marks being assigned for question-parts coding for *understand* ranged from 19% (South Africa) to 36% (Ireland).

Apart from South Africa, the other countries assigned between 24% and 49% of the marks to question-parts coding for *apply.* South Africa assigned 65% of the marks to this same cognitive skill. As with physics the majority of question-parts coding to *apply* the action verb was ‘to calculate’.

The percentage distribution of marks for question-parts coding to analyse was between 1% (South Africa) and 15% (New South Wales) while a much smaller percentage of question-parts (1%-6%) coded to *evaluate*. Similar to finding for physics, where were no question-parts which coded to *create.*

Table 4. Percentage distribution of marks per cognitive skill levels across the six chemistry examinations.

Exam in	***Remember***	***Understand***	***Apply***	***Analyse***	***Evaluate***	***Create***
England	13%	23%	49%	9%	**6%**	0%
Ireland	**38%**	**36%**	24%	2%	1%	0%
the Netherlands	25%	31%	27%	14%	3%	0%
New South Wales	10%	34%	40%	**15%**	3%	0%
Scotland	31%	26%	35%	4%	4%	0%
South Africa	15%	19%	**65%**	1%	0%	0%

A combination of the percentage distribution of marks for the two lower cognitive skills of *remember* and *understand* showed that the physics examinations had between 8% (the Netherlands) and 60% (Ireland) of question-parts coding to these skills. In comparison, between 34% (South Africa) and 74% (Ireland) of questions-parts on the chemistry examinations coded to these. Across all the physics examinations there was more question-parts assessing the cognitive skill of *apply* from 70% (Netherlands) to 23% (New South Wales) with a comparable range in chemistry of 65% (South Africa) to 24% (Ireland). The percentage of question-parts coding for the higher cognitive skills of *analyse, evaluate* and *create* was between 0% and 15%. Neither subject examination had any question-parts coding for *create.*

DISCUSSION AND CONCLUSIONS

The focus of this desk-based comparative study was solely on the content of the publicly available 2016 examination documents issued by the education authorites of each of the countries as in Table 1. The cognitive skills, as presented, were based on the written word of the examination whether it was the intended outcome of the assessors/setters of the examinations (Matters & Masters, 2007). Using the compiled Stanny-Newton list of action-verbs as well as the supplementary list in Table 2 when coding for each of the six cognitive levels ensure the same assessment standard was applied to all the examinations.

Examining the data from the physics papers indicate that, with some exceptions, there was less emphasis on marks being assigned to cognitive skills of '*remember*' and '*understand*' type of questions. Three of the examinations, the Netherlands, Scotland and South Africa assigned a high percentage of the respective total marks to the cognitive skill *apply* that is 70%, 60% and 65% respectively. A similar analysis carried out by Motlhabane on South African physics examinations of 2014 and 2015 showed that 64% of the questions assessed the cognitive skill *apply* (Motlhabane, 2017). However, most of the question-parts which coded for this skill used the same computational action -verb as these the examples shown

Calculate the heating power of the element. (the Netherlands, physics 2016 Q. 5)

Calculate the effective resistance of the parallel branch.
(South Africa, physics 2016, Q.8.1.5)

The Netherland's physics syllabus referenced prior knowledge that students should know and so would not be a feature of the examination – hence the absence of any question-parts coding to *remember* and a low percentage of marks, 8%, being assigned to questions assessing *understand*. Consequently, more question-parts focused on assessing cognitive skills of *apply, analyse* and *evaluate.*

The data from the chemistry analysis paints a very different picture. Across all the examinations the emphasis was on the *remember* and *understand* type of questions with the percentage of marks assigned to each of the cognitive levels of *remember* and *understand* ranging from 10% to 38% (*remember*) and from 19% to 36% (*understand*). This emphasis on the lower cognitive skills is in keeping with similar studies (Burns et al., 2018; Edwards, 2010; Letmon et al., 2021; Madaus & Macnamara, 1970; Tsaparlis & Zoller, 2003). As mentioned earlier, there were no mandatory questions on the Irish physics and chemistry examinations thus allowing students to choose eight questions from eleven. This choice element of the examinations meant that each of the eleven questions had to assess approximately the same cognitive skills in order to maintain comparability between all the questions (Bramley & Crisp, 2019). In comparison, the mandatory nature of the question-parts on the other examination papers should have enabled more question-parts to focus on assessing the higher skills of *analyse* and *evaluate*. Yet the data did not bear this out.

IMPLICATIONS AND FURTHER STUDIES

The 2015 OECD report on the *Future of Education and Skills Education 2030* challenged governments to future-proof national education systems by raising two key questions – 'what competencies and skills will be needed in the future? how will these competencies be implemented and assessed?' (OECD, 2015). Studies have shown a disconnect between what educators consider skills and employers' expectations with employers considering the skills most lacking were *problem-solving*, *analytical* and *critical thinking skills* (Cunningham & Villasenor, 2016; Hanushek & Woessmann, 2008) which could identify to Bloom's cognitve skills of *apply, analyse* and *evaluate.* The data as presented in this study highlighted the paucity of question-parts assessing *analyse* and *evaluate* skills while the majority of question-parts coding to *apply* were solely computational ones. However, using the action-verb list as the sole determining tool to identify and compare the cognitive skills across national examinations presented a limited or dimensionless analysis of them. The gathered data was based on a single year's examination raising the questions –

(a) How reflective was the data of the national curiculum objectives of the relevant countries?

(b) What role did the examiners' reports have in evaluating the examinations with respect both to the national curriculum objectives and to the students' written responses to the examionation questions?

One of the criteria for selection was the comparability of topics being examined. However, this study focused on the examination questions without reference to the topics which prompts a third question

(c) What might the comparison of cognitive skills as reflected across comparble topics reveal?

A further study addressing these three questions is ongoing. In addition, further work is needed to develop and promote the use of questions which assess the cognitive skills of evaluate and create in these high-stakes examinations at the end of upper second level education.

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