DOI: 10.1478/AAPP.1041A3

AAPP | Atti della Accademia Peloritana dei Pericolanti
Classe di Scienze Fisiche, Matematiche e Naturali
ISSN 1825-1242

Vol. 104, No. 1, A3 (2026)

IS IT POSSIBLE A 'REVERSE FLYNN EFFECT'? CONSIDERATION FOR NEW OPPORTUNITIES IN THE CONTEXT OF SUSTAINABILITY

UMBERTO LUCIA [a*] AND GIULIA GRISOLIA [b]

ABSTRACT. Recently, some evaluations of the workers' and students' abilities brought back to consider the negative (or reverse) Flynn effect. The reverse Flynn effect is an empirically confirmed decrease in the Intelligence Quotient since the 1990s. It has been proven to be related to environmental conditions only. Here, we consider this effect as an environmental consequence of the social and education conditions, considering it a possible resource, meaning the opportunity to reconsider the education pathway and the workers' training. To do so, in this paper, we develop a thermodynamic analysis of the information fluxes that enter the brain and the related stabilisation of the inflow of information itself. Moreover, we develop a thermo-economic analysis of the consequences of the reverse Flynn effect, pointing out the need to focus educational policies on the continuous stimulus of the use of reasoning and problem-solving-based education, to develop the processing capacity and foster the creative capabilities of young people, who build the backbone of the future workforce.

1. Introduction

The latest survey of adult skills performed by the Organisation for Economic Co-operation and Development (OECD 2024) shows that, on average across OECD countries, 18% of adults lack even the most basic levels of proficiency in any skill domain. In total, 31 countries and economies participated in the 2023 Survey of Adult Skills. This survey, conducted by the OECD Programme for the International Assessment of Adult Competencies (PIAAC), offers a comprehensive overview of adults' literacy, numeracy, and adaptive problem-solving skills essential skills for personal, economic, and societal development. Skill gaps are a significant issue in many surveyed countries, with over one in three firms reporting a mismatch between the skills their employees have and those needed. The Slovak Republic has the highest percentage of enterprises reporting skill gaps (54%), followed by Italy (37%), Portugal (32%), the Netherlands (31%), and Hungary (27%). These differences reflect varying economic conditions and unique challenges in adapting to technological changes. The most common skill gaps identified across countries are in technical skills (46% of firms), problem-solving skills (34%), and teamwork skills (33%), whereas gaps in reading (2%) and mathematics (4%) are less frequently reported. Interestingly, firms in the

Slovak Republic and the Netherlands highlight customer handling and management skills as key gaps. Although many firms report skill gaps, they mainly affect specific employee groups; only a small percentage (less than 5%) say that the majority of their workforce lacks necessary skills. Many firms, particularly in the Netherlands (18%) and Hungary (15%), are uncertain about their skill gaps, indicating a need for better skills assessment mechanisms. Larger firms are more likely to report skill gaps than smaller ones (59% versus 34%). This could be due to greater organizational complexity or better skills assessment processes. Manufacturing firms report the most skill gaps (41% on average), particularly in technical skills, followed by the communications and finance sectors (32%). The consequences of skill gaps include increased workloads for existing staff (63%), higher operating costs (50%), and difficulties in adopting new practices (46%). A third of firms state that skill gaps hinder their ability to adopt new technologies, highlighting the economic risks involved and the need for firms to address these issues.

The global economy is rapidly changing due to technological advances, ageing populations, shifting supply chains, and efforts to achieve net-zero emissions, affecting the skill needs of firms. Skill gaps—mismatches between workers' skills and employers' requirements—pose significant challenges for businesses. This report, based on the PIAAC Employer Survey Module, analyses skill gaps in Hungary, Italy, the Netherlands, Portugal, and the Slovak Republic, and how firms respond through skills anticipation, training, and targeted recruitment. The findings indicate that skill gaps are prevalent, especially in technical skills, teamwork, and problem-solving. These gaps increase workloads, raise operating costs, and hinder the implementation of new practices. Most firms focus on training and development to address these issues, while fewer choose to recruit new staff or alter work organization.

These results brought back to consider the negative (or reverse) Flynn effect. Even though it might seem like a negative outcome, confirming the reverse Flynn effect can be viewed as a crucial opportunity to enhance educational and training programs for young people and staff. In an industrial world where scientific skills are becoming increasingly essential, this confirmation highlights the need for improvement, with future positive effects on sustainability.

In 1981, the New Zealand psychologist James Flynn showed that the Intelligence Quotient (IQ) scores of humans have been increasing over approximately a century (Flynn 1984b, 1994, 2006); indeed, twelve-year-olds in the 1980s performed better than twelve-year-olds in the 1970s, who performed better than 12-year-olds in the 1960s, etc. (Flynn 1984a, 1985; Shenk 2017): Flynn then went on to develop the first analysis of this kind, where he involved 7431 participants in support of an increasing IQ at a median rate of 0.31 points per year between 1932 and 1978, across 18 comparisons of the SB, WAIS, WISC, and Wechsler Preschool and Primary Scale of Intelligence (WPPSI) (Trahan *et al.* 2014). On average, his tests yielded an IQ improvement of three points every ten years. In particular, Flynn noted that this trend was not related to certain regions or cultures. Instead, this aptly named Flynn effect was related to the ability of abstraction, not to specific ability in mathematical results; indeed, children in later years showed the same ability in mathematics as those in previous years. So, Flynn explained this effect by highlighting that the divergent IQ was related to the different contextual needs of life, that is, in 1900, building intelligence was driven by real life needs such as processing an ever increasing wealth of information, while in 1970s, it was driven by a more complex problem solving approach (Shenk 2017), with a related increase in the IQ. In summary, what Flynn discovered was simply a new approach to culture as a set of continuously diffusing knowledge, across educational paths toward the public, over the middle of the 20th century. This explanation of the Flynn effect as a consequence of evolving environmental conditions has been confirmed also in recent genetic studies (Woodley 2011).

The Flynn effect highlights that in about one century, the increase in access to education and the dissemination of the scientific and technical knowledge have raised the measurable intelligence level of a large part of the population. This is a clear proof that, even if intelligence presents a biological component, it is best defined as a “set of competencies in development” (Sternberg 2005). This implies that competence and ability are the result of working harder and developing more self-discipline (Csikszentmihalyi, Rathunde, and Whalen 1993), which must be the base of education, as experimentally proven by Kaufman and Duckworth (2017). Indeed, an IQ test is a measure of the achievement of a person, while it cannot measure the person’s innate intelligence, because intelligence is a set of competencies in development (Flynn 1987; Shenk 2017). Consequently, ‘IQ’ is a measure of how a person is doing, and it can represent a predictor of future abilities in problem solving.

But, intriguingly, this observed Flynn effect has been shown to have reached a turning point in the 1990s when it started to continuously decline (Dutton, van der Linden, and Lynn 2016; Bratsberg and Rogeberg 2018), a trend termed the *reverse Flynn effect*. This new effect is rather alarming, because, as previously highlighted, IQ is a measure of the abilities to solve problems and reasoning; as such, this reverse trend has obvious implications for the capability and productivity of the future work force as a whole. This is all the more concerning as work requirements are evolving quickly, which necessitates the ability to adapt to change and conceptualize complex ideas in a multidisciplinary setting (OECD 2013; Mevarech and Kramarski 2014; OECD 2015a,b; Bakhshi *et al.* 2017; OECD 2019).

In this paper, we recognize the OECD results as valuable experimental evidence, intentionally avoiding discussions on IQ approaches, educational models, or the complexities of the direct or reverse Flynn effect. Our focus is clear: we want to harness these findings as a powerful impetus to enhance the training of young people and workers, equipping them to champion the implementation of sustainability effectively.

The United Nations (UN) have developed an indicator for assessing progress and the well-being of a country, by taking into account not only its economic growth, but also other fundamental social requirements, such as the educational level (knowledge), and life expectancy (population’s longevity), i.e., the Human Development Index, *HDI* (UNDP (United Nations Development Programme) 1990; Sagar and Najam 1998; Hickel 2020). Recently, in order to introduce also the evaluation of consumption of resources and the ecological impact of the human activities, this indicator has been improved to yield the so-called Thermodynamic Human Development Index (*THDI*) (Lucia and Grisolia 2021a,b). In both these indicators, an educational index has been taken into account, due to its importance for human development and well-being.

In this paper we analyse the reverse Flynn effect based on a thermo-economic evaluation of its impact on future sustainable development.

2. Material and methods

Firstly, we consider that one of the results of education consists of (Noddings 2003):

- lifelong process, with the aim of providing a continuous improvement of personal abilities and skills;
- social aim, with the result to improve the individual potential in order to allow anyone to become a productive member of society;
- personal aim, with the result to allow any individual to become a respected person in the social context due to his/her cooperation to improve society, by providing him/her knowledge and skills;
- cultural aim, by improving the sense of a society, art, morals, laws, etc.;
- personal character of any individual, with the improvement of honesty, truthfulness, justice, goodness, etc.
- intellectual aim, with the improvement of the methodological skills of problem solving.

Any thermo-economic evaluation must introduce an indicator in order to quantify the country's conditions. In particular, for education the United Nations Development Program (UNDP) has defined the *Education Index*, EI, as (UNDP (United Nations Development Programme) 2020):

$$EI = \frac{MYSI + EYSI}{2} \tag{1}$$

where $MYSI = MYS/15$ is the Mean Years of Schooling Index and $EYSI = ESI/18$ is the Expected Years of Schooling Index (UNDP (United Nations Development Programme) 2020). The EI has been introduced in the context of the Human Development Report (Saisana 2014), and it represents one of the three components of the Human Development Index HDI, which is an indicator of the development level of a country in relation to education, health and salary conditions (Javaid, Akbar, and Nawaz 2018). It is the geometric mean of three normalised indices representative of each dimension (UNDP (United Nations Development Programme) 1990) and its analytical definition is (UNDP (United Nations Development Programme) 2020):

$$HDI = (LEI \cdot EI \cdot II)^{1/3} \tag{2}$$

where LEI is the Life Expectancy Index, EI represents the Education Index and II is the Income Index. The Life Expectancy Index LEI is defined as (UNDP (United Nations Development Programme) 2020):

$$LEI = \frac{LE - 20}{85 - 20} \tag{3}$$

where LE is the Life Expectancy at birth, which indicates the overall mortality level of a population. It corresponds to the years that a newborn is expected to live at current mortality rates (World Bank Group 2026c). Therefore, in order to normalise the Life Expectancy at birth, the United Nations have set its minimum and maximum values to 20 and 85 years, respectively (UNDP (United Nations Development Programme) 2020). Indeed, in the 21st century there are no countries with a life expectancy at birth lower than 20 years, and, on the other hand, the value of 85 years is set as a realistic aspirational target (UNDP (United

Nations Development Programme) 2020). The Normalised Income Index II, is defined by the United Nations, as:

$$II = \frac{\ln(GNI_{pc}/100)}{\ln(75000/100)} \tag{4}$$

where GNI_{pc} is the gross national income per capita at purchasing power parity (PPP), with minimum and maximum value set by the United Nations (UNDP (United Nations Development Programme) 2020) as 100.00 \$ and 75,000.00 \$, respectively. The choice of 100.00 \$, as the GNI_{pc} minimum value, is due to the difficulty in capturing the amount of the unmeasured subsistence and non-market production, within the official data of the economies close to the minimum (UNDP (United Nations Development Programme) 2020). While, the maximum GNI_{pc} value of 75,000.00 \$ has been chosen as threshold because, for higher values, no gain in human development and well-being has been shown (UNDP (United Nations Development Programme) 2020). However, this index does not take into account the technological and ecological level of a country. Recently, with the aim of considering the technological level, an improvement of the HDI has been introduced, using an irreversible thermodynamic approach (Lucia and Grisolia 2021b):

$$THDI = \left(\frac{LEI \cdot EI}{I_T}\right)^{1/3} \tag{5}$$

where (Lucia and Grisolia 2021a):

$$I_T = \frac{T_0 \dot{S}_g}{\dot{W} \cdot GNI_{pc}} = 0.01 \cdot \frac{T_0 \dot{S}_g}{\dot{W}} \cdot 750^{-II} \tag{6}$$

and (Bejan 2006; Grisolia, Fino, and Lucia 2020; Lucia, Fino, and Grisolia 2020):

$$T_0 \dot{S}_g = T_0 \, \dot{m}_{CO_{2-eq}} s_g \tag{7}$$

where $\dot{m}_{CO_{2-eq}}$ is the CO_{2-eq} equivalent mass flow rate emitted for obtaining the required effect $\dot{W}$ and s_g is the specific entropy generation due to the process developed. Here we consider CO_{2-eq} in order to take into account both CO_2 mass flow and other pollutants and resource flows contribution. Assuming that CO_2 emissions and other pollutants are the main drivers of irreversibility represents our methodological limit, but the approach introduced represents a starting point for future improvements in these studies.

Consequently, the Thermodynamic Human Development Index $THDI$ serves as a bio-economic indicator that also takes into account a society's technical and environmental levels. Additionally, it highlights the impact of the irreversibility of processes on sustainability measurement. Indeed, reducing irreversibility is crucial for enhancing the sustainability of a process. Similar to the Human Development Index HDI, a higher value of the $THDI$ reflects higher human well-being, which includes the interactions of the population with their environment, specifically in terms of carbon dioxide equivalent emissions. Regarding its definition, the $THDI$, as expressed in Eq. (5), is not a normalized quantity, whereas the HDI is derived from the product of normalized indices, resulting in a normalized index itself. Therefore, the first step is to normalize the $THDI$. To achieve this, the $THDI$ must follow the same structure as the HDI, meaning it should be expressed as a product of normalized quantities. As a result, the quantity that needs to be normalized is I_T^{-1}. To do this, we can express I_T as follows:

$$I_T = \frac{I}{GNI_{pc}} \tag{8}$$

where $I = T_0\,\dot{m}_{\mathrm{CO}_{2-eq}} s_{\mathrm{CO}_{2-eq}}/\dot{W}$ (Lucia and Grisolia 2018). As a consequence of the definition of $THDI$ we must normalise I^{-1} and GNI_{pc}. To do so, considering the relation between GNI_{pc} and II, it is possible to normalise GNI_{pc} as:

$$GNI_{pc,n} = \frac{GNI_{pc}}{GNI_{pc,max}} = \frac{100 \cdot 750^{II}}{75000} = 750^{II-1} \tag{9}$$

Then, following the the approach of the proof of the Gouy-Stodola theorem (Bejan 2006; Lucia and Grisolia 2019), it is possible to obtain:

$$\dot{W}_{id} = \dot{W} + T_0\,\dot{S}_g \tag{10}$$

where $\dot{W}_{id}$ is the maximum useful power that can be produced. Thus, in the approach here used, it follows (Lucia and Grisolia 2024):

$$\dot{W}_{id} = \dot{W} + T_0\,\dot{m}_{CO_{2-eq}}\,s_{CO_{2-eq}} \tag{11}$$

Consequently, it is possible to normalise I by using the following relation:

$$I_n = \frac{I}{I_{max}} = \frac{\dfrac{T_0\,\dot{m}_{CO_2-eq}\,s_{CO_2-eq}}{\dot{W}}}{\dfrac{T_0\,\dot{m}_{CO_2-eq}\,s_{CO_2-eq}}{\dot{W}_{id}}} = \frac{\dot{W} + T_0\,\dot{m}_{CO_{2-eq}}\,s_{CO_{2-eq}}}{\dot{W}} \tag{12}$$

so,

$$I_n^{-1} = \frac{\dot{W}}{\dot{W} + T_0\,\dot{m}_{CO_{2-eq}}\,s_{CO_{2-eq}}} \tag{13}$$

Consequently, the normalisation of $I_{T,n}^{-1}$ results:

$$I_{T,n}^{-1} = \frac{\dot{W}}{\dot{W} + T_0\,\dot{m}_{CO_{2-eq}}\,s_{CO_{2-eq}}} \cdot 750^{II-1} \tag{14}$$

obtaining the normalised Thermodynamic Human Development Index:

$$THDI_n = \sqrt[3]{\frac{LEI \cdot EI}{I_{T,n}}} \tag{15}$$

$THDI$ explicitly takes into account the emissions of the considered Country. The empirical estimation of the *ideal* useful work could be difficult, but we can obtain it from the Countries data-bases about energy consumed in production sectors, their efficiency and the related CO_{2-eq} emissions. Moreover, normalized $THDI$ must be considered in relation to its hypotheses. Indeed, it is a useful tool for a direct measure of sustainability even if it presents some limits: (i) it depends strongly on the assumptions of normalization related to the evaluation of the ideal useful work, (ii) it reduces environmental complexity to CO_{2-eq}

emissions alone, and (iii) it does not consider structural economic and political factors. When a process is analysed, weighting its CO_{2-eq} contribution concerning the total carbon dioxide emission of the Country in which the process occurs, is useful. Indeed, progress has always been associated with the economic growth and with a related increase of the energy production needs. Up to today, the energy production has been made mainly by the combustion of fossil fuels, with a related increase of the air pollutants and the emission of greenhouse gases, such as CO_2. Consequently, today, one of the main issues of the industrialized and developing countries is just the management of CO_2 emissions, one of the present problems of the production systems (Hammond 2004; Nordhaus 2008), even if, just the CO_2 emission could also represent an opportunity for the promotion of high-efficiency design of both conventional and new technological plants.

But, also in *THDI* the Educational Index is taken into account. Indeed, this index is considered to be related to the development of abilities of young people, due to the stimuli obtained from educational activities. This can be explained by introducing some thermodynamic considerations.

In order to obtain an interpretation of the effect of education on the abilities of young people, we must introduce a model of the brain, based on its capability of generating creativity, memory, information processing, etc. From a thermodynamic viewpoint, the human brain may be considered as an irreversible open system, with flows of free energy and information influx from the environment. The evolution of any internal process is a pathway between two different thermodynamic states, with a related entropy production rate in the configuration space of the process variables (Watzlawick, Bavelas, and Jackson 2011). So, we can introduce the exergy balance of the brain (Kirkaldy 2020):

$$\frac{dG}{dt} = -\left[(J_{I,2} - J_{I,1}) + (J_{c,2} - J_{c,1})\right] - T_0 \frac{d_i S}{dt} \tag{16}$$

where J_I and J_c represent the information form and the chemical form of the Gibbs free energy flux through the brain surface, respectively (Kirkaldy 2020), T_0 is the brain environmental temperature, S denotes the entropy, and the suffix i means due to irreversibility. The optimisation of the system implies that (Bejan 2006):

$$\frac{d_i S}{dt} \to 0 \tag{17}$$

while, for a stationary state, it follows (Bejan 2006):

$$\frac{dG}{dt} = 0 \tag{18}$$

so:

$$J_{I,2} = J_{I,1} - (J_{c,2} - J_{c,1}) \tag{19}$$

which means that the information influx to the brain is a consequence of the chemical Gibbs free energy fluxes. But, the Gibbs free energy can flow only if there are external stimuli to the nervous systems, and in relation to information useful for increasing the IQ due to structure formation, followed by its stabilization (Rietman *et al.* 2020). This thermodynamic result could provide physical evidence that both the direct and reverse Flynn effect are influenced also by environmental conditions. We emphasize that both effects present an opportunity to design educational and training programs for young people and workers, aimed at enhancing their skills in technology management for innovation.

3. Results

In Fig. 1, we apply the aforementioned approach to a set of countries (Algeria, Argentina, Australia, Belgium, Brazil, Canada, China, Denmark, Finland, France, Germany, Greece, India, Italy, Japan, Mexico, Norway, South Africa, Spain, Sweden, United States). For 2017, across all these countries, the Educational Index has increased when compared with the reference year of 1990 (Fig. 2). Consequently, an increase in the Thermodynamic Human Development Index can be observed as well, which means that the well-being and the environmental impact of these countries have improved, too, proving a direct correlation between these two indicators. But, these increases for 2017 are related to the current highly trained professionals i.e. the scientists, engineers, and managers born before the 1990s, when the Flynn effect (of ever increasing population IQ) was occurring. Now, the reverse Flynn effect will produce 'delayed' consequences for the future as well, when the present youth becomes the professional backbone of the workforce. So, given the reversal of IQ seen, a decrease in the $THDI$ is expected.

In 1997, the relationship between IQ and income inequality has been thoroughly examined (Murray 1997), obtaining that the more intellectually able people become richer and more powerful, while those less intellectually able find it harder to cope financially, as graphically described by The Bell Curve (Fig. 3). Moreover, a positive relationship between national estimates of cognitive skills and product sophistication has been studied (Lapatinas and Litina 2019). The results have shown a positive correlation between the level of a country's collective intelligence and the level of its economic sophistication, by pointing out that intelligence is a first-order issue as it can improve the productive capacity, with the consequence of highlighting that product sophistication reflects also the ability to create and document information (Lapatinas and Litina 2019). But, the fact that the original Flynn effect and the cited UN measures of development correlate positively, albeit with a timed delay of decades, means that conceivably one can intervene with targeted educational interventions to mitigate the detrimental workforce effects of the reversed IQ trend.

4. Discussion

In Thermodynamics, an attempt to rationalize the behaviour of some kinetic systems on the basis of irreversible thermodynamics has been developed (Kirkaldy 1965) by obtaining an approach related to the entropy production rate. This approach has been extended also to biological subsystems in order to describe their stability-seeking path, in relation to their biophysical and biochemical behaviour. We have introduced this approach by pointing out that any information flow into the brain can be described as a Gibbs free energy flux. But, this flux is always related to an external neurological stimulus. Consequently, the growth in neurological structures is a consequence of continuous stimuli from the environment to the brain. The use of memory, the study, the problematic cultural elaboration based on problem solving, etc. are fundamental to increase the IQ.

We have developed our analysis by introducing the Thermodynamic Human Development Index, an indicator which links the entropy generation rate to the Human Development Index,

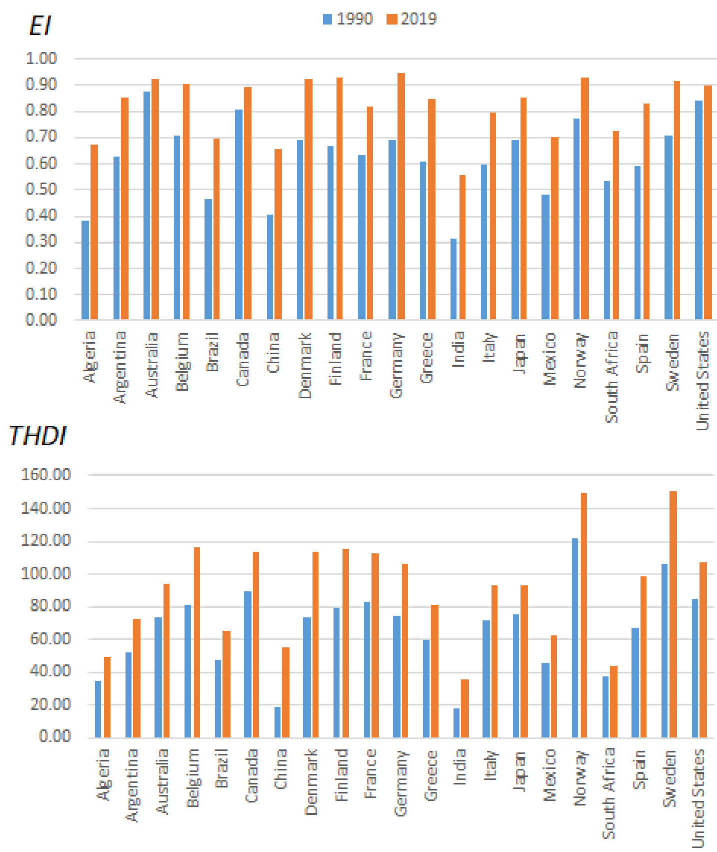

FIGURE 1. An example of the Educational Index and of the Thermodynamic Human Development Index for a set of countries: Algeria, Argentina, Australia, Belgium, Brazil, Canada, China, Denmark, Finland, France, Germany, Greece, India, Italy, Japan, Mexico, Norway, South Africa, Spain, Sweden, United States. The two indicators are represented for two different years: 1990 and 2017. The data are collected from Refs. (Friedlingstein *et al.* 2020; UNDP (United Nations Development Programme) 2026a,b; World Bank Group 2026a,b) and elaborated by using Eq. (5).

in order to consider the anthropic environmental impact in the socioeconomic analysis. This is an indicator for sustainability, and in the concept of sustainability, the education represents a fundamental point. Indeed, a right educational approach allows the young people to improve their ability, to increase their creativity, and to grow both as individuals and as professionals fundamental for the improvement and sustainable management of the Earth resources.

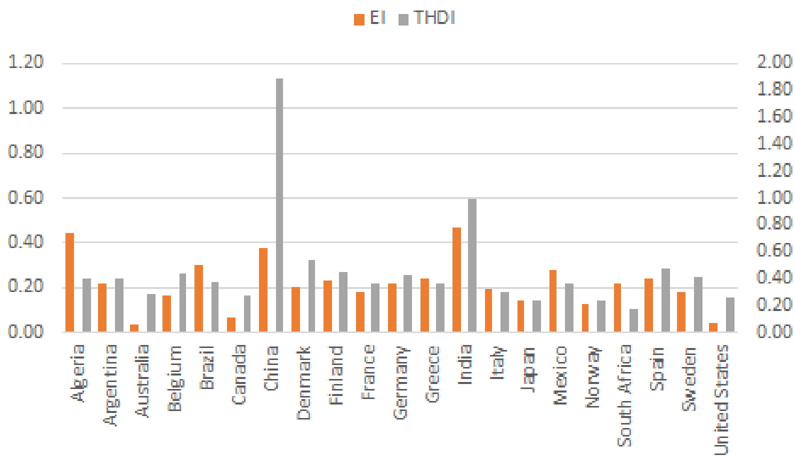

FIGURE 2. The variation of the *EI* and the *THDI* between the two years considered (1990 and 2017), for the set of countries taken into consideration. The data are collected from Refs. (Friedlingstein *et al.* 2020; UNDP (United Nations Development Programme) 2026a,b; World Bank Group 2026a,b) and elaborated by using Eq. (5).

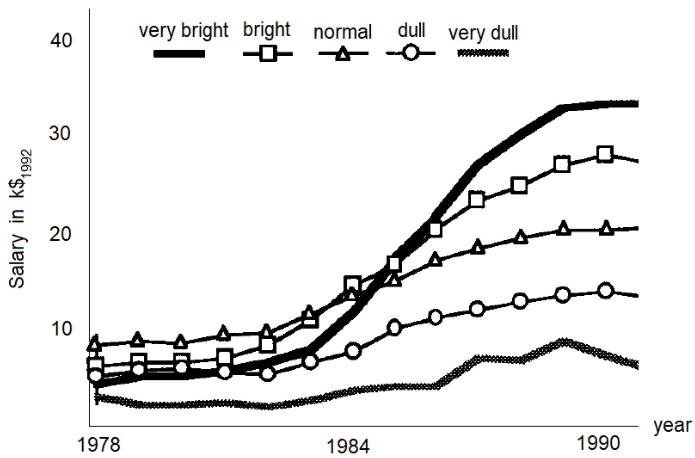

FIGURE 3. Median earned income by cognitive class from 1978 to 1992. The income is expressed in US $ (exchange rate fixed to 1992). Data from (Murray 1997), processed by the authors.

So, the increase in IQ is also related to the elaborative and creative abilities of humans, so, also to the skills required in a globalized working world. Consequently, the policies of education are fundamental in order to prevent social and economic inequality and difficulties in the future (Zhang and Dornfeld 2007).

In this context, we must highlight that China shows the better increase (Fig. 2) in the $THDI$, due to its ability in the technological and also social skills. Indeed, China has increased its EI, and in relation to it also the improvement in teaching mathematical, physical and engineering topics, with a related increase of its IQ, as reported by Liu and Lynn (2013), who analysed the Flynn effect in China from 1985 to 86 and to 2011–12, pointing out that the IQ of 12-year-olds in China has continuously increased, with a Performance IQ gain of 6.55 points (Liu and Lynn 2013). These increases are of similar magnitude to approximately 2.18 IQ points per decade for the United States for the years 1948–2002 (Flynn 1984b). Similar differences in gains have recently been reported in South Africa (te Nijenhuis, Murphy, and van Eeden 2011), which confirms our results as reported in Fig. 2. Performance IQ is more a measure of fluid intelligence and the greater increases on this suggest improvements in the neurological efficiency of the brain, and for such Countries it has been attributed both to the increase of education and to improvements in nutrition (Liu and Lynn 2013). So, increases in intelligence have also been attributed to the rapid growth in the Chinese economic sector, which determined a related increase in the overall standard of living in China. Moreover, improvements in nutrition and a decline in infant mortality has been highlighted as an improvement in the health system in China, with positive effects on student IQ levels (Liu and Lynn 2013). These improvements are accompanied by a consequent educational requirements driven by economic growth needs (new technologies, designing, etc.), which changes the educational level towards a fluid intelligence increase due to logical thinking and problem solving based educational approach.

5. Conclusions

Many studies investigate the cognitive and emotional aspects of intelligence and their impact on employee performance. Intelligence is a key predictor of employees' capabilities and behaviours, but research indicates that Intelligence Quotient (IQ) alone is insignificantly related to performance. Instead, Emotional Intelligence shows a significant correlation with success, suggesting that Emotional Intelligence is more critical than IQ in the workplace (Gondal and Husain 2013). They show that organizations can benefit by incorporating EI assessments alongside IQ tests to enhance overall effectiveness. In contrast, using administrative register data spanning over four decades, this study examined various measures of educational attainment and its relationship with cognitive abilities. The results indicate a consistent decline in the correlation between these two factors over time. These findings underscore a more complex relationship between cognitive ability and educational attainment (Van Hootegem *et al.* 2023). Moreover, the OECD's latest Survey of Adult Skills reveals that 18% of adults across participating countries lack basic proficiency in key skill areas. Skill gaps represent a significant challenge, with over one in three firms reporting mismatches between employee skills and employer needs. The global economy is changing due to technological advancements and shifting demographics, increasing the demand for specific skills. This report, based on the PIAAC Employer Survey Module, analyses skill gaps in Hungary, Italy, the Netherlands, Portugal, and Slovakia and indicates that firms primarily focus on training and development to address these issues rather than recruiting or reorganizing work.

In this context, our considerations on the reverse Flynn effect stem from OECD results (OECD 2024) and propose to consider this effect as a starting point to develop innovation on the approach to education and training, highlighting the fundamental role of the mathematical and scientific skills in a technologically evolving world that must address answers to sustainability. We know that many criticisms have been raised against IQ approaches, educational models, or the complexities of the direct or reverse Flynn effect. But, our result is to point out that OECD results can be seized as opportunities to improve our skills for sustainability.

References

Bakhshi, H., Downing, J., Osborne, M., and Schneider, P. (2017). *The Future of Skills: Employment in 2030*. London: Pearson and Nesta.

Bejan, A. (2006). *Advanced Engineering Thermodynamics*. Hoboken: John Wiley.

Bratsberg, B. and Rogeberg, O. (2018). "Flynn effect and its reversal are both environmentally caused". *PNAS* **115**, 6674–6678. DOI: 10.1073/pnas.1718793115.

Csikszentmihalyi, M., Rathunde, K., and Whalen, S. (1993). *Talented Teenagers: The Roots of Success and Failure*. Cambridge: Cambridge University Press.

Dutton, E., van der Linden, D., and Lynn, R. (2016). "The negative Flynn effect: A systematic literature review". *Intelligence* **59**, 163–169. DOI: 10.1016/j.intell.2016.10.002.

Flynn, J. R. (1984a). "IQ gains and the Binet decrements". *Journal of Educational Measurement* **21**, 283–290. DOI: 10.1111/j.1745-3984.1984.tb01035.x.

Flynn, J. R. (1984b). "The mean IQ of Americans: Massive gains 1932 to 1978". *Psychological Bulletin* **95**, 29–51. DOI: 10.1037/0033-2909.95.1.29.

Flynn, J. R. (1985). "Wechsler intelligence tests: Do we really have a criterion of mental retardation?" *American Journal of Mental Deficiency* **90**, 236–244.

Flynn, J. R. (1987). "Massive IQ gains in 14 nations: What IQ tests really measure". *Psychological Bulletin* **101**, 171–191. DOI: 10.1037/0033-2909.101.2.171.

Flynn, J. R. (1994). "IQ gains over time". In: *The encyclopedia of human intelligence*. Ed. by R. J. Sternberg. New York: Macmillan.

Flynn, J. R. (2006). "Beyond the Flynn effect: solution to all outstanding problems except enhancing wisdom". In: *Lecture at the Psychometrics Centre*. Ed. by C. A. Group. Cambridge: American Psychological Association: University of Cambridge.

Friedlingstein, F. *et al.* (2020). "Global Carbon Budget 2020". *Earth System Science Data* **12**(4), 3269–3340. DOI: 10.5194/essd-12-3269-2020.

Gondal, U. H. and Husain, T. (2013). "A Comparative Study of Intelligence Quotient and Emotional Intelligence: Effect on Employees' Performance". *Asian Journal of Business Management* **5**, 153–162. DOI: 10.19026/ajbm.5.5824.

Grisolia, G., Fino, D., and Lucia, U. (2020). "Thermodynamic optimisation of the biofuel production based on mutualism". *Energy Reports* **6**, 1561–1571. DOI: 10.1016/j.egyr.2020.06.014.

Hammond, G. P. (2004). "Engineering sustainability: thermodynamics, energy systems, and the environment". *International Journal of Energy Research* **28**, 613–639. DOI: 10.1002/er.988.

Hickel, J. (2020). "The sustainable development index: Measuring the ecological efficiency of human development in the anthropocene". *Ecological Economics* **167**, 106331. DOI: 10.1016/j.ecolecon.2019.05.011.

Javaid, A., Akbar, A., and Nawaz, S. (2018). "A Review on Human Development Index". *Pakistan Journal of Humanities and Social Sciences* **6**, 357–369.

Kaufman, S. B. and Duckworth, A. L. (2017). "World-class expertise: a developmental model". *WIREs Cognitive Science* **8**, e1365. DOI: 10.1002/wcs.1365.

Kirkaldy, J. S. (1965). "Thermodynamics of terrestial evolution". *Biophysical Journal* **5**, 965–979.

Kirkaldy, J. S. (2020). "Thermodynamics of the Human Brain". *Biophysical Journal* **5**, 981–986.

Lapatinas, A. and Litina, A. (2019). "Intelligence and economic sophistication". *Empirical Economics* **57**, 1731–1750. DOI: 10.1007/s00181-018-1511-y.

Liu, J. and Lynn, R. (2013). "An increase of intelligence in China 1986–2012". *Intelligence* **41**, 479–481. DOI: 10.1016/j.intell.2013.06.017.

Lucia, U., Fino, D., and Grisolia, G. (2020). "Thermoeconomic analysis of Earth system in relation to sustainability: a thermodynamic analysis of weather changes due to anthropic activities". *Journal of Thermal Analysis and Calorimetry* **145**, 701–707. DOI: 10.1007/s10973-020-10006-4.

Lucia, U. and Grisolia, G. (2018). "Cyanobacteria and microalgae: Thermoeconomic considerations in biofuel production". *Energies* **11**, 156. DOI: 10.3390/en11010156.

Lucia, U. and Grisolia, G. (2019). "Exergy inefficiency: An indicator for sustainable development analysis". *Energy Reports* **5**, 62–69. DOI: 10.1016/j.egyr.2018.12.001.

Lucia, U. and Grisolia, G. (2021a). "Irreversible Thermodynamics and Bioeconomy: Towards a Human Oriented Sustainability". *Frontiers in Physics* **9**, 659342. DOI: 10.3389/fphy.2021.659342.

Lucia, U. and Grisolia, G. (2021b). "The Gouy-Stodola Theorem—From Irreversibility to Sustainability—The Thermodynamic Human Development Index". *Sustainability* **13**, 3995. DOI: 10.3390/su13073995.

Lucia, U. and Grisolia, G. (2024). "A Thermo-Economic Measure of Sustainability". *Processes* **12**, 713. DOI: 10.3390/pr12040713.

Mevarech, Z. and Kramarski, B. (2014). *Critical Maths for Innovative Societies: The Role of Metacognitive Pedagogies*. Paris: OECD Publishing.

Murray, C. (1997). "IQ and economic success". *Public Interest* **128**, 21–35.

Noddings, N. (2003). *Happiness and Education*. Cambridge: Cambridge University Press.

Nordhaus, W. (2008). *A question of balance: Weighing the options on global warming policies*. New Haven: Yale University Press.

OECD (2013). *PISA 2012 Assessment and Analytical Framework: Mathematics, Reading, Science, Problem Solving and Financial Literacy*. Paris: PISA-OECD Publishing.

OECD (2015a). *Research Protocol for OECD Project on Assessing Progression in Creative and Critical Thinking Skills in Education*. Paris: OECD Publishing.

OECD (2015b). *Skills for Social Progress: The Power of Social and Emotional Skills, OECD Skills Studies*. Paris: OECD Publishing.

OECD (2019). *Trend Shaping Education*. Paris: OECD Publishing.

OECD (2024). *Do Adults Have the Skills They Need to Thrive in a Changing World?: Survey of Adult Skills 2023. OECD Skills Studies*. Online; accessed 22nd December 2024. Paris. DOI: 10.1787/b263dc5d-en.

Rietman, E. A., Taylor, S., Siegelmann, H. T., Deriu, M. A., Cavaglia, M., and Tuszynski, J. A. (2020). "Using the Gibbs Function as a Measure of Human Brain Development Trends from Fetal Stage to Advanced Age". *International Journal of Molecular Sciences* **21**, 1116. DOI: 10.3390/ijms21031116.

Sagar, A. D. and Najam, A. (1998). "The human development index: a critical review". *Ecological Economics* **25**, 249–264. DOI: 10.1016/S0921-8009(97)00168-7.

Saisana, M. (2014). "Education Index". In: *Encyclopedia of Quality of Life and Well-Being Research*. Ed. by A. C. Michalos. Dordrecht: Springer, pp. 1816–1819. DOI: 10.1007/978-94-007-0753-5_840.

Shenk, D. (2017). "What is the Flynn Effect, and how does it change our understanding of IQ?: What is the Flynn Effect". *WIREs Cognitive Science* **8**, e1366. DOI: 10.1002/wcs.1366.

Sternberg, R. J. (2005). "Intelligence, competence, and expertise". In: *Handbook of Competence and Motivation*. Ed. by A. J. Elliot and C. S. Dweck. New York: Guilford Publications.

te Nijenhuis, J., Murphy, R., and van Eeden, R. (2011). "The Flynn effect in South Africa". *Intelligence* **39**(6), 456–467. DOI: 10.1016/j.intell.2011.08.003.

Trahan, L. H., Stuebing, K. K., Fletcher, J. M., and Hiscock, M. (2014). "The Flynn effect: A meta-analysis". *Psychological Bulletin* **140**, 1332–1360. DOI: 10.1037/a0037173.

UNDP (United Nations Development Programme) (1990). *Human Development Report 1990: Concept and Measurement of Human Development*. Tech. rep. United Nations. URL: https://hdr.undp.org/content/human-development-report-1990 (visited on 02/13/2026).

UNDP (United Nations Development Programme) (2020). *Technical notes. Calculating the human development indices - graphical presentation*. Tech. rep. United Nations. URL: https://hdr.undp.org/sites/default/files/data/2020/hdr2020_technical_notes.pdf (visited on 02/13/2026).

UNDP (United Nations Development Programme) (2026a). *Human Development Data*. Tech. rep. United Nations. URL: https://hdr.undp.org/data-center (visited on 02/13/2026).

UNDP (United Nations Development Programme) (2026b). *Human Development Data. Composite indices complete time series*. Tech. rep. United Nations. URL: https://hdr.undp.org/sites/default/files/2025_HDR/HDR25_Composite_indices_complete_time_series.csv (visited on 02/13/2026).

Van Hootegem, A., Røgeberg, O., Bratsberg, B., and Lyngstad, T. H. (2023). "Correlation between cognitive ability and educational attainment weakens over birth cohorts". *Scientific Reports* **13**, 17747. DOI: 10.1038/s41598-023-44605-6.

Watzlawick, P., Bavelas, J. B., and Jackson, D. D. (2011). *Pragmatics of Human Communication: A Study of Interactional Patterns, Pathologies, and Paradoxes*. New York: Norton.

Woodley, M. A. (2011). "Heterosis doesn't cause the Flynn effect: A critical examination of Mingroni (2007)". *Psychological Review* **118**, 689–693. DOI: 10.1037/a0024759.

World Bank Group (2026a). *Climate Change Knowledge Portal - Download Data*. URL: https://climateknowledgeportal.worldbank.org/download-data (visited on 02/13/2026).

World Bank Group (2026b). *GNI per capita, PPP (constant 2021 international $)*. URL: https://data.worldbank.org/indicator/NY.GNP.PCAP.PP.KD (visited on 02/13/2026).

World Bank Group (2026c). *Life expectancy at birth, total (years)*. URL: https://data.worldbank.org/indicator/SP.DYN.LE00.IN (visited on 02/13/2026).

Zhang, T. W. and Dornfeld, D. A. (2007). "Energy Use per Worker-Hour: Evaluating the Contribution of Labor to Manufacturing Energy Use". In: *Advances in Life Cycle Engineering for Sustainable Manufacturing Businesses*. Ed. by S. Takata and Y. Umeda. London: Springer-Verlag, pp. 189–193.

[a] Politecnico di Torino,
Dipartimento Energia "Galileo Ferraris"
Corso Duca degli Abruzzi 24, 10129 Turin, Italy

[b] Politecnico di Torino,
Dipartimento di Ingegneria dell'Ambiente, del Territorio e delle Infrastrutture,
Corso Duca degli Abruzzi 24, 10129 Turin, Italy

[*] To whom correspondence should be addressed | email: umberto.lucia@polito.it

Manuscript received 27 March 2025; communicated 15 May 2025; published online 4 March 2026