The Moore's Law for Education and the Need for Inclusion

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***Abstract*—From within the electronics industry, Gordon Moore observed an exponential rate of development of technology. Over time, the same pace of development has been observed for most human activities, resulting in an exponential growth in the volume of accumulated knowledge. This phenomenon also has adverse consequences, especially the increasing difficulty of the educational process, mainly in the scientific and engineering fields, which ultimately results in an increase in school dropout. To cope, we will have to initiate the inclusion of students in the new context, through measures that will support for long term a Moore's law for education. To begin with, we propose several measures, such as increasing the share of visual representations of knowledge or applying the recommendations of the Bologna Process more rigorously.**

***Index Terms*—Moore's Law, Visual Representation of Knowledge, Bologna Process, Inclusive Education, System Engineering**

I. The Moore's Laws and Education

In 1965, Gordon Moore, Intel CEO & Co-founder, made a perspicacious empirical observation: *the number of transistors in integrated circuits doubles every two years*. This observation became the well-known First Moore's Law. In the following decades, and until today, the law has been verified and even knowingly applied in the management of the electronics industry. Moreover, the exponential development pattern noticed by G. Moore has been observed in many more areas of human activity: (1) Moore's Second Law (Arthur Rock's Law): the cost of a semi-conductor chip fabrication plant doubles every four years; (2) More than Moore: the Moore's law is now beginning to be revalued in the sense of performance indexes per chip instead of sheer number of transistors per chip; (3) Moore's Law for Knowledge: the general human knowledge doubles every year [1]; and (4) Moore's Law for Everything: addresses our entire society as a whole [2].

An undesirable consequence of the Moore's Law for Knowledge appears in education: *young students face more and more difficulty the increased volume and complexity of the knowledge they have to assimilate*. Therefore, we are witnessing an alarming increase in school dropouts. In 2001 G. Moore complained: "*It's hard to come up with ways to increase productivity in education*" [3]. Eventually one can observe that Moore's Law is beginning to make its presence felt in education too [3].

We believe that the current situation requires a new fundamental approach, capable to sustain in the long term a proper Moore's Law for Education, helping students to include into the Moore's Law for Knowledge era. For this, we must increase the efficiency of learning, so that it keeps pace with the increase in the volume of knowledge. This approach is encouraged by the statement according to which learning resources are practically unlimited [4].

II. Psychological Theories Explaining the Phenomenon

A. Cognitive Load Theory

Cognitive load theory (CLT), developed by John Sweller, provides a valuable framework for addressing the challenges posed by exponential growth in knowledge and its implications for education. CLT posits that working memory has a limited capacity for processing information. As the volume and complexity of educational content increase, the cognitive load on students also rises. This escalation in cognitive load can lead to cognitive overload, where students struggle to process or retain information effectively, ultimately resulting in reduced learning efficiency and increased dropout rates [5], [6]. To counteract these issues, strategies that manage cognitive load, such as simplifying complex information and utilizing multimedia tools to present knowledge visually, are essential. These strategies help accommodate the rapid advancements described by Moore's Law in education, thereby supporting more effective learning experiences.

Van Merrienboer and Sweller emphasize that recent developments in CLT highlight the importance of designing instructional methods that manage cognitive load effectively, especially when dealing with complex learning scenarios [7]. By integrating these principles into educational practice, educators can better support students in handling the growing complexity of their studies.

B. Self-Determination Theory

Self-determination theory (SDT), developed by Deci and Ryan, emphasizes the essential psychological needs for autonomy, competence, and relatedness as central to motivation and learning [8]. The exponential growth of knowledge, as highlighted by Moore's Law, may challenge students' sense of competence and autonomy, especially when the pace of learning feels overwhelming or unmanageable. This can adversely impact their motivation and academic performance. According to SDT, when students perceive their learning environment as supportive of their need for autonomy, they are more likely to experience intrinsic motivation and engage more deeply with the material. Similarly, providing constructive feedback and fostering meaningful interactions with peers and educators can enhance students' sense of competence and relatedness, which are crucial for maintaining motivation and engagement [9].

Research supports the idea that educational practices aligning with SDT principles can lead to more effective learning outcomes. For instance, Guay, Ratelle, and Chanal argue that optimal learning environments, which cater to students' psychological needs, contribute to better educational outcomes [10]. They found that when students experience a high degree of self-determination within their learning contexts, they are more likely to engage actively and perform well academically.

In light of these insights, incorporating measures that support the psychological needs identified by SDT - such as providing opportunities for self-directed learning, ensuring frequent and constructive feedback, and facilitating collaborative and supportive peer interactions - can help mitigate the negative effects of rapid knowledge expansion. This approach not only addresses the challenges posed by Moore's Law for education but also promotes more inclusive and effective educational practices that cater to diverse student needs.

C. Information Processing Theory

Information processing theory, as developed by Atkinson and Shiffrin, provides a framework for understanding how information is encoded, stored, and retrieved [11]. This theory becomes increasingly relevant as the volume of information grows exponentially, presenting challenges for processing and organizing vast amounts of data effectively. According to the theory, cognitive strategies such as chunking and rehearsal are crucial for managing large data sets, which can help students process and retain information more efficiently.

Chunking involves breaking down complex information into smaller, manageable units, making it easier to encode and recall [12]. Rehearsal, which includes techniques like repetition and active engagement with the material, also plays a significant role in strengthening memory retention. Integrating these cognitive strategies into educational practices can aid students in navigating the challenges associated with the rapid expansion of knowledge. For example, employing visual aids, interactive tools, and other multimedia resources can enhance students' ability to process and retain information by presenting it in more digestible formats [13].

Incorporating information processing techniques into teaching methodologies supports increased inclusion and provides effective support mechanisms for students facing the complexities of modern education. By applying these strategies, educators can help students manage cognitive load more effectively, fostering an environment where learners are better equipped to handle the demands of rapid knowledge growth.

D. Complex Adaptive Systems Theory

Complex adaptive systems theory (CAST) provides a contemporary cognitive psychological perspective that integrates concepts from Systems Engineering. CAST focuses on how systems, including educational systems, adapt and evolve in response to environmental changes [14]. This theory emphasizes the dynamic interactions among various components of a system and the necessity for flexibility in adapting to rapid changes.

In the context of Moore's Law for education, CAST posits that educational systems must be designed to be adaptable and resilient to the exponential growth in knowledge. As knowledge expands at an accelerating rate, educational environments must continuously evolve to meet diverse learning needs and integrate new technologies and methodologies. This adaptability involves creating learning systems that can effectively incorporate feedback and undergo iterative improvements to refine educational practices [15].

CAST also highlights the importance of feedback loops and iterative processes in educational settings. By applying CAST principles, educators can develop more responsive and inclusive educational systems. For instance, leveraging iterative feedback mechanisms and promoting flexibility in teaching approaches can help address the challenges associated with rapid knowledge expansion, ultimately supporting long-term student success [16].

By implementing CAST, educational institutions may create settings that are more suited to managing the complexity of modern education and responding to the needs of fast knowledge expansion, as outlined by Moore's Law.

Understanding the psychological underpinnings of educational challenges in the context of rapid knowledge expansion provides valuable insights into how to support students effectively. By applying theories such as cognitive load theory, self-determination theory, information processing theory and complex adaptive systems theory, educators can develop strategies to enhance learning outcomes and address the needs of a diverse student population. In addition to supporting the inclusion of all students in a changing educational environment, these strategies aid in managing the growing body of information.

III. Concrete Inclusion Measures

A. Improving the Bologna Process Application

School dropout is all the more expensive the more advanced the student is on a higher level of preparation and the larger the target group. That is why we will focus with priority on students in the undergraduate stage.

The Bologna Declaration (19 June 1999) proposed a higher educational system with two main cycles, undergraduate and graduate, leading to the master and/or doctorate degree (Fig. 1). Access to the second cycle requires successful completion of first cycle of minimum three years. The first cycle degree (Bachelor) is already relevant to the European labour market as an appropriate level of qualification.

A key issue is the balance between mass and elite higher education [17]. This balance is perfectly designed, but our observations (direct, empirical, and at a restricted scale) point out that many professors apply elite standards for the mass level, leading to scholar dropout. Besides personal attitudes, this might also be caused by a possible lack of attention paid to the mass level compared to the elite one. There are important differences between mainstream and elite education. The inclusiveness of mass education is meant to be broad, but its depth remains shallow, as does its specialization and rigor. On the other hand, elite education is supposed to be deep, rigorous, and specialized, thus losing out on inclusiveness. That is why the next measures will point to possible technical solutions leading to effectiveness, notably in mass education.

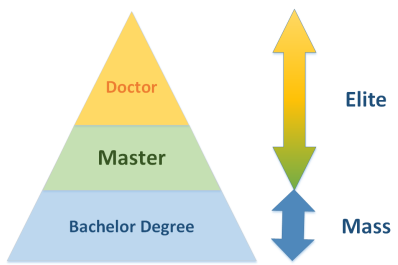

Fig. 1. The higher education structure (Bologna Process)

B. Visual Representation of Knowledge

Homo Sapiens is a diurnal species, essentially relying on sight [18]: 90% of information transmitted to the brain is visual; 50% of the brain's surface is used for the vision; and visual information gets to brain 60.000 times faster than text.

These facts lead us to the conclusion that we should look to favorize the visual representation of knowledge, especially when addressed to the undergraduate students [19]. Figure 2 illustrates how visual adds enhance texts' understanding [18].

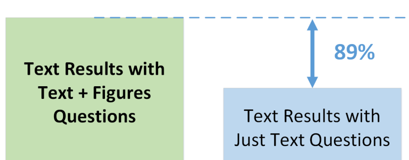

Fig. 2. Better formulated questions lead to better results

Visuals can break down complex concepts into more digestible parts, making it easier for students to grasp intricate ideas. Diagrams, flowcharts, and mind maps can illustrate the relationships between different concepts, helping students understand how they interconnect. Moreover, visuals are often more memorable than text alone. The dual-coding theory suggests that information presented both visually and verbally is more likely to be remembered, as visual representations can reinforce learning by providing multiple ways to process and recall information. When considering student motivation, visuals can make learning more engaging and interesting, potentially increasing student motivation and participation. Visual tools like graphs and charts encourage students to analyze data and identify patterns, trends, and outliers, and they help visualize problems and brainstorm solutions, fostering critical thinking skills.

As previously mentioned, in fields like science, technology, engineering, and mathematics, visualizations such as graphs, models, and simulations are crucial for understanding abstract and complex concepts. Visual tools can illustrate historical timelines, sociological theories, and literary analyses, making these subjects more accessible and engaging. To give an example, we mention that visual reasoning is beginning to be adopted even in areas where formal mathematical approaches seemed immutable, such as automation. These approaches are specific to Artificial Intelligence methods, which, let's not forget, seek to emulate human reasoning. In the broadest sense, in automation, one can observe a revaluation of methods based on quantitative or even qualitative time analysis, such as the analysis of the phase trajectory of the control error, which has appeared since the nineteenth century, comparing to methods based on the precise frequency analysis (transfer functions, pole placement, etc.). More specifically, we can mention: (1) The sliding mode [20]; (2) The qualitative analysis [21]; (3) The self-adaptive fuzzy-interpolative controllers [22]; and (4) Sculpting the state space [23].

Systems engineering (SE) is an increasingly significant scientific field that successfully manages multidisciplinary and very complex systems (including educational ones). SE applications are based almost entirely on visual software packages: UML (Unified Modeling Language), IDEF (Integration Definition), QFD (Quality Function Deployment), etc.

C. The Top-Down Approach

SE is proposing another way to increase education's efficiency, which is derived from its holistic feature: embracing the Top-Down approach [24]. The top-down approach means essentially fewer details and more comprehension.

Bottom-Up teaching starts with small details and broadens the scope of the lessons step by step as students master the skills. This way is rigorous, yet instruction-driven, cumbersome, and time-consuming, eventually suited for elite education and company specific training.

The strategy of top-down teaching begins with the big, abstract concept and works down to the specific details, according to the available time. This motivates students to learn through direct interaction and their own experience and is fast and suited to mass education. The Top-Down Approach in education provides a structured and motivating way to learn, promoting a deeper and more integrated understanding of subjects while aligning well with real-world problem-solving and diverse learning styles. It is structured and linear, ideal for subjects where a foundational understanding is crucial, aiming for a comprehensive understanding by building from general to specific. Students gain an overall understanding of the subject, helping them see how individual parts fit into the bigger picture. This broad perspective can enhance comprehension and retention of detailed information. By understanding the ultimate goals and applications of what they're learning, students can be more motivated to engage with and master the detailed content. Knowing the relevance and end goals of their studies can make the learning process more meaningful and interesting. Moreover, starting with general concepts allows students to quickly grasp the subject's scope and identify areas that need more focus. This can make the learning process more efficient, as students can prioritize their efforts on more challenging aspects once they understand the overall framework.

Given the current complexity of education, illustrated in section 2, a mechanical application of any of the methods proposed above is virtually impossible. Hybrid solutions have the highest chance of success. Let's give an example from digital electronics: the Hardware Description Languages (HDL). HDLs admit two types of descriptions for the same circuit: Behavioral and architectural, which are interchangeable according to needs (Fig. 3). The behavioral description is top-down functional, while the architectural is bottom-up structural.

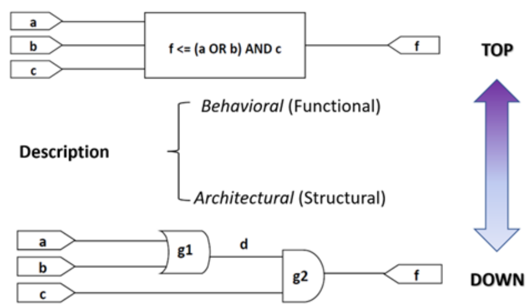

Fig. 3. The HDL descriptions

IV. Conclusion

The paper discusses the ever-widening gap between the volume of general knowledge, which obeys Moore's law of exponential knowledge development, and the effectiveness of education, which cannot keep up. The effect of this gap is critical for young people, especially for undergraduates, who have a high dropout rate. This is a peculiar case of inclusion, because it is addressing a wide group of perfect valid persons: virtually any student. In order to promote their inclusion in the context of Moore's law for knowledge, several fundamental measures are proposed in order to give education a greater dynamic: the more rigorous application of the Bologna Process system, the prioritization of visual methods of representation and manipulation of knowledge and the broader application in education of methods derived from Systems Engineering, such as the top-down approach.

Incorporating visual representation of knowledge in higher education not only caters to diverse learning styles but also enhances comprehension, retention, engagement, and critical thinking. By leveraging the power of visuals, educators can create a more effective and enriching learning environment that prepares students for both academic and real-world challenges. The application of such a set of measures is a large, lasting action and will require the involvement of all teachers, whose task is difficult because they will have to start by changing themselves.

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