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3D printer: an application in teaching

Antonio Batocchio^{1[0000-0001-7292-2141]}, Samuel Santos Silva^{2[00001-0002-5885-9702]}, Matheus Franco^{3[0000-0002-9649-4038]} and Vinicius L.F. Minatogawa^{4[0000-0002-7441-7242]}

^{1,2,3} Campinas University, Campinas SP 13083-860, Brazil

⁴ Pontificia Universidad Catolica de Valparaiso, Valparaiso 2340000, Chile
batocchi@fem.unicamp.br

Abstract. The global changes in the world, changes in political, economic and business activities as well as the development of technology, transport and communications, impose the need for enterprises in their struggle for survival to change their strategies and go out from the borders of their own country. The evolution of capitalism depends on the dynamic interaction of seven factors that constitute the spheres of activity. Each of them represents a part of the complexity of the social and economic systems that are part of the contemporary world, namely: technologies and forms of organization; social relations; institutional and administrative arrangements; production and work processes; relations with nature; the processes of social reproduction and reproduction of individuals; and the mental conceptions of the world. Two other aspects that are bringing great transformations in society and companies are innovation and new technologies based on digital transformation. In the educational environment, especially in public schools on the outskirts of cities, there is a huge lack of resources for other essential items for the development of children. The conditions of infrastructure and use of technologies have not yet reached these schools. With the advent of the fourth industrial generation and the intensive use of digital technologies, the degree of deficiencies in teaching and students' development in schools located in these peripheral regions increases. In this environment, he decided to develop the work of applying 3D printers as an educational tool and strategy for improving the quality of teaching in these schools.

Keywords: 3D printer, business model, teaching.

1 Introduction

In this topic, we will present aspects of the business environment that have just impacted companies, such as the phenomenon of market globalization, issues related to competitiveness, innovation, digital transformation, and technologies.

1.1 Globalisation

The evolutionary dynamics of the business environment have brought important consequences, which have forced corporate executives to change their conceptions and views on the market, especially the global one.

The global changes in the world, changes in political, economic and business activities as well as the development of technology, transport and communications, impose the need for enterprises in their struggle for survival, to change their strategies and go out from the borders of their own country [1].

According to Pinto and Gonçalves [2], the process of economic globalization has advanced significantly since the last two decades of the last century. This process caused profound structural changes in the world economy. In particular, there have been changes in the power of the most important countries, such as China and the United States of America.

According to Harvey (2010, apud Araujo, 2017) [3], the evolution of capitalism depends on the dynamic interaction of seven factors that constitute the spheres of activity. Each of them represents a part of the complexity of the social and economic systems that are part of the contemporary world, namely: i) technologies and forms of organization; ii) social relations; iii) institutional and administrative arrangements; iv) production and work processes; v) relations with nature; vi) the processes of social reproduction and reproduction of individuals; and vii) the mental conceptions of the world.

According to Lorga (apud Vivas and Sousa) [4], companies face, thereby increasing levels of complexity and uncertainty, since the competition, the political-legal, technological advances, consumer preferences, culture, language, religion, etc. can affect the success of the international adventure.

1.2 Competitiveness

There are some relevant aspects to be considered for a company's success, such as strategy and competitiveness, in the global environment.

Strategy is defined by Johnson and Scholes (apud SNIRCOVÁ, FIDLEROVÁ and BOZIKOVÁ) [5] as the direction and scope of an organization over the long-term: which achieves advantage for the organization through its configuration of resources within a challenging environment, helps to meet the needs of markets and to fulfill stakeholder expectations.

There are several definitions for competitiveness and here, one of them is presented: competitiveness can be understood as the company's ability to exploit, to its advantage, the structure and competition standards of the market in which it operates (or wants to operate) and, thus, achieve long-term profitability [6]. However, if you think in global terms, the World Economic Forum [7] [8] addresses the issue in terms of the global competitiveness of organizations.

Sustainable global competitiveness model is new visualization of an enterprise as a system with all relations performing in its environment based on our experience within the research in manufacturing companies, in Slovakia, for example, the base of the model comprises three vertically oriented pillars of sustainable development: ecological, economic and social pillar [5]. These three pillars are known as the Triple Bottom Line (TBL).

To achieve competitiveness, organisations have to adapt themselves to the cultural environment in which they are active and for this, they require the entire management

who is willing, aware, who have the knowledge and skills to communicate and operates above the cultural barriers [9].

1.3 Innovation

Two other aspects that are bringing great transformations in society and companies are innovation and new technologies, based on digital transformation. In terms of innovation, in the literature, there is a lot of discussion about radical and incremental innovation [10] [11] [12]. In terms of Brazil, the national agency to support the country's development (FINEP), adopted the Oslo Manual [13] as the guide. In this manual, four types of innovations are defined, which encompass a wide range of changes in the activities of companies: product innovations, process innovations, organizational innovations and marketing innovations.

Nadkarni and Prügl [14] conceptualize digital transformation at the intercept of the adoption of disruptive digital technologies on the one side and actor-guided organizational transformation of capabilities structures, processes and business model components on the other side. These authors argue that digital technologies may reflect in all of these definitions of disruptive innovation. They may represent new-to-the-world product innovations, dislocate existing processes, and open up entirely new business models.

The different definitions for Digital Transformation (DT) may be categorized in three distinct elements: (1) Technological–DT is based on the use of new digital technologies such as social media, mobile, analytics or embedded devices; (2) Organizational–DT requires a change of organizational processes or the creation of new business models; (3) Social–DT is a phenomenon that is influencing all aspects of human life by e.g., enhancing customers experience [15].

The technological capability and power of digital transformation applications, such as the Internet of Things (IoT), big data, cloud computing, and mobile technologies, are in terms of computing power, data storage and information distribution in many cases significantly higher than in previous technology-driven transformations. Earlier business transformations were mostly concerned about introducing internal management information systems such as enterprise resource planning (ERP) or customer relationship management (CRM). These transformations were usually limited to improvements to business processes within firm boundaries [14].

The intensive use of digital transformation technologies, in several areas, mainly in industries, led to the creation of the term of the fourth industrial revolution and the consequent, industry 4.0 [16] [17]. These authors said that Industry 4.0 triggers a staggering effect by transforming the manufacturing and production processes in industries. In other words, Industry 4.0 will play a significant role in transforming traditional companies into Smart Factories with the help of the Internet of Things (IoT) and Cyber-Physical Systems (CPS).

2 Motivation

In the educational environment, especially in public schools on the outskirts of cities, there is a huge lack of resources for other essential items for the development of children. The conditions of infrastructure and use of technologies have not yet reached these schools.

Labor force skills are improving but still lag behind those in other countries. Brazil is far from achieving the average learning levels, secondary education completion rates, and student flow efficiency of OECD and other middle-income countries. Although Brazil had the strongest math improvement and third largest overall improvement (behind Luxembourg and Chile) between 2000 and 2009 on PISA, it is still not the leader in the LAC region. Chile, Uruguay, and Mexico all perform better in absolute terms (see figure 1) [18].

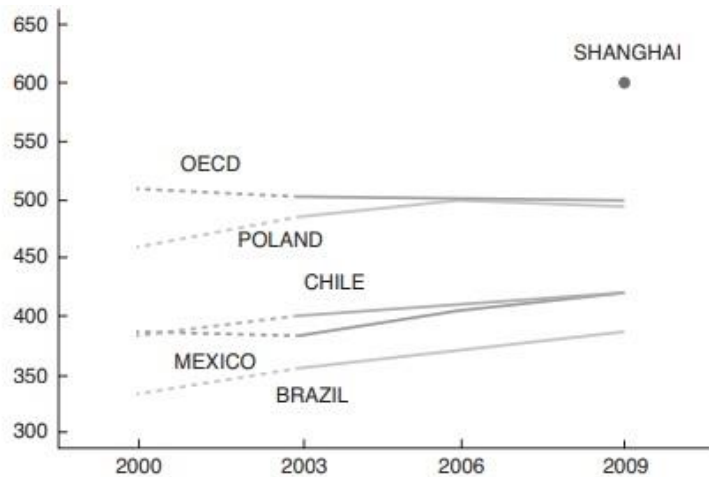


Fig. 1 - PISA Math Performance for Brazil and Selected Countries, 2000–2009 [18]

With the advent of the fourth industrial generation and the intensive use of digital technologies, the degree of deficiencies in teaching quality and students' development in these public schools is amplified with the digital transformation. The availability and adoption of technology and information resources (i.e., notebooks, tablets, access to high-speed internet, among others) are mostly for the called private individuals. These individuals' families have superior economic conditions to the families residing in the peripheries. As such, this reality creates great asymmetries between these two distinct populations.

Moreover, the deficiencies of public schools are not only in physical and financial resources, but also in human resources. Usually, the teachers of these schools work in several schools and have several work shifts, making it almost impossible to seek improvement in qualification, either through extension courses or master's or doctorate

courses. The result of all this is the deficient qualification and demotivation of the teachers and, finally, the quality of teaching in these schools.

The objective of this work is to carry out a study for the application of 3D printers as an educational tool and strategy for improving the quality of teaching in these schools.

3 Literature Review

In this topic, we will address the literature review, which is related to the objectives of this work, focusing on the following themes: product development and its importance, business model concepts, the issue of education in the country, information technology, and its nuances, and finally the 3D printer.

3.1 Product development

In a previous article, we focused on three relevant aspects for product development [19]: application of customer development practices [20] to understand the needs of a particular type of customer; start the development of a product based on the lessons learned in the interactions with potential customers, in the customer development phase and, finally, use the SECI model [21] [22] to understand the iterations of knowledge that occur between the development of the product and the customers.

It turns out that product development is a complex step and that it incurs a large part of the costs of a product. According to Cooper and Chew [23], when senior managers tried to drive costs out of their operations *ex post facto* by cutting staff, eliminating frills, outsourcing, or reengineering downstream processes, they often discovered that as much as 70% to 80 % of a product's costs were effectively immutable after they leave the designers' hands. As product and process technologies have become more integrated, a product cost has become even more strongly tied to its design.

The product development cost normally determines the market share, profit and return on investment of these small and middle-sized manufacturing companies. To control a product development cost at earlier product development stages is in turn a problem of accurately estimating a possible cost associated with a product development cycle [24]. The implementation of a new product requires a series of activities. The more innovative the product is, the more complicated the process is. It consists of several main phases: idea generation, idea screening, concept development and testing, marketing strategy, business analysis, product development, test marketing and commercialization [25]. Each of them has a large uncertainty in the results [26].

There are many conceptions of the new product development process and they are presented as containing varying numbers of steps, stages, and/or activities. The approach taken in the Best Practices Survey was to ask respondents whether seven carefully described new product development activities were recognized as part of their organization's product development process, and if so, how long it typically took for each activity to be completed [27]. The author presents a table, which contains the eight

main activities and the times involved: concept search; concept screening; concept testing; business analysis; product development; product use testing, field testing, and/or market testing; commercialization and, other process activities.

3.2 Business Model

According to Minatogawa [28], although there are antecedents that indicate the concept of Business Models (BM) as something present in the business ecosystem, it starts to be better studied and understood only around the beginning of the 2000s. Some authors relate the notoriety with the proliferation of the use of information and communication technologies, the development of technology companies (especially those related to the internet in some way), and the trends of the NASDAQ index (National Association of Securities Dealers Automated Quotations; in Portuguese, "National Association of Automatic Quote Bond Brokers ") from the early 1990s to the end of the event known as dot-com bubble [29] [30] [31].

Franco [32] clarifies that interest in the term BM has gained prominence in the last 15 years [31]. Although BMs have always existed, even if implicitly, interest in studying the topic has increased significantly in recent years since it is associated with the growth and maintenance of competitiveness [33] [34] [35]. New BMs, or Business Model Innovations (BMI), have also been a target of recent interest because, in addition to generating disruption and completely reshaping industries [33], they are a new way, in addition to traditional innovations in products, services and processes, for companies to remain competitive [35].

There are several definitions for BM in the literature, stated by the authors mentioned above, in this research area. In this text, we adopt Shafer, Smith and Linder [36] definition that a BM is a representation of a firm's underlying core logic and strategic choices for creating and capturing value within a value network.

3.3 Teaching

The discussion of basic education problems in Brazil has been marked, in recent years, by the wider dissemination of information produced by the external evaluation system, on a large scale, centralized and focused on student performance and on the performance of education systems. The evaluations of the learning performance in Portuguese Language and Mathematics of students from the public system of basic education, in the segments of elementary and high school, and their unsatisfactory results over more than ten years, fuel controversies in different spaces, especially in the media, about public policies and educational management [37].

Considering a global spectrum, education is widely accepted as a fundamental resource, for individuals and societies. In fact, in most countries basic education is now perceived not only as a right, but also as a duty. Governments must guarantee access to basic education [38]. The future of education is surrounded by uncertainties and the challenges faced by teachers throughout their careers, increasingly requires the ability to identify and solve problems [39].

Students are using the computers and many helpful applications to learn, practice and testing the gained knowledgements and these new tools are not so different from

workbooks. Teachers can use multimedia technology to give more colourful, stimulating lectures. The current emphasis is ensuring that technology is used effectively to create new opportunities for learning and to promote student's achievement [40].

Transferring knowledge and skills is not a trivial task, and the challenge is even greater when the goal is reached such result for all students [41]. In this sense, education and science and technology have a very close relationship. Education plays an important role in the development of science and technology, and this helps society to achieve well-being. Understanding this relationship, technological development should be better accommodated for the educational area in the form of educational materials. Thus, the technologies of the most different areas of science should be available to educators. The importance of technology in schools is one of the pillars of education that must be understood [42].

However, with the advent of new technologies, schools might have great difficulties in rearranging themselves in order to benefit from these technologies. Digital transformation alone poses a challenge for any organization [43]. The issue is magnified when we also consider some schools' scenario of low-budget availability, poor management and lack of adequate governmental public policies. Hence, it is a great challenge for Brazilian society, for instance, to rethink what we want for the future of new generations and the basic education of public schools.

3.4 Information Technology

It stands for "Information Technology," and is pronounced "I.T." It refers to anything related to computing technology, such as networking, hardware, software, the Internet, or the people that work with these technologies [44]. And information technology is important for all areas of knowledge, as it brings tangible and intangible benefits.

Technology has been one of the major competitive differentials in the New Economy, in addition to the business model [45]. The New Economy is mainly driven by modern information and communications technologies (ICT). They give access to almost any kind of information at an almost unlimited speed at almost any place on Earth [46].

New technologies tend to reduce the prices of goods and services to which they are applied. They also lead to the creation of new products. Consumers benefit from these improvements, regardless of whether they live in the developed world or the developing one [47]. And this author said: but for technology to make a real and sustained contribution to development, it must not only provide better and cheaper products, it must also lead to better-paying jobs. In other words, it must help developing nations qua producers as well as qua consumers. A technology has a network effect when the value of the technology to a user increases with the number of total users in the network [48].

Within the scope of new technologies, there is Digital Economy. The digital economy has a significant implication in business transformation and the creation of new digital businesses. Moreover digital economy offers great opportunities for small and medium enterprises. However, this does not mean that they will definitely have success in the new conditions and electronic market. We should emphasize that the growth of the digital economy means that computers operate in conditions of constant and global competition [49].

According to Shaquiri and Namani [49], IT is built around the chip and, in terms of the digital economy, IT opens possibilities for specialization and cooperation between companies from different regions, also reduces transaction costs in business cooperation, provides access to foreign markets and ensures that different companies may specialize in products various digital and cooperate by exchanging digital products between companies of different regions depending on customer demand. This collaboration facilitates the development of small and medium as well as electronic access to these markets and the development of new forms and models of business as a business, or electronic business.

Management information systems support business decision-making by providing management with critical data. They serve to enhance the organization's communication, reduce human labor, support short and long-term business goals and distribute complex information [44].

3.5 3D Printer

To focus on the 3D printer it is necessary to explain about the Additive Manufacturing (AM) process. According to Tofail et al. [50], additive manufacturing makes objects from a digital 'model by depositing the constituent material/s in a layer-by-layer manner, using digitally controlled and operated material laying tools. This broader definition of Additive Manufacturing essentially highlights four main components [50]: i) A digital model of the object, which can vary from a pizza slice to an airplane wing; ii) Material/s that are consolidated from the smallest possible form (for example, liquid droplets, wire, powder to make the object); iii) A tool for laying materials and iv) A digital control system for the tool to lay the material/s layer-by-layer to build the shape of the object.

There are several advantages, which can be credited to the additive manufacturing process, such as [50]: it is versatile, flexible, highly customizable and, as such, it is highly suitable for most sectors of industrial production. The primary focus of AM has remained on customization of low volume, high-value-added products that can be manufactured quickly.

The 3D printing technology originated from the layer-by-layer fabrication technology of three-dimensional (3D) structures directly from Computer-Aided Design (CAD) drawing. The 3D printing technology is truly innovative and has emerged as a versatile technology stage. It opens new opportunities and gives hope to many possibilities for companies looking to improve manufacturing efficiency [51].

This article's particular interest is to address the application of the 3D printer in education and there are several works that deal with this topic. Ligon et al. [52], focuses on the application of polymer processing and the development of polymers and advanced polymer systems in chemistry. Stamper and Dekker [53] focuses on engineering (undergraduate mechanical engineering classes) and graphic design course [54]. Ortega et al. [55] focus in construction. And another [56], in the teaching of children. These authors all aim at learning new technologies (3D printers).

The current Brazilian model of public education evolved during the industrial revolution. The compartmentalization of subjects and the structuring of curricula have provided an efficient means of educating large numbers of students. The advent of 3D

printing and advanced manufacturing provides the opportunity to re-establish the vital interconnection among the historically related subjects. Once learned in the proper and natural context, the knowledge will be more readily retained [57].

4 Method

Before announcing the methods used in this work, it is necessary to recognize what a method is and its importance for research. In consultation with several researchers, it is noted the difficulty of understanding and definitions, which please the different lines of thought. According to Boudah [58], the research method varies, but the research goal is almost always the same: to answer a question.

The method, in science, is not reduced to a presentation of the research steps. Therefore, it is not just a description of the procedures, of the paths traced by the researcher to obtain certain results. When talking about the method, we try to explain, what are the reasons why the researcher chose certain paths and not others. These are the reasons that determine the choice of a certain way of doing science [59].

For Gil (apud in [59]), the scientific method is a set of intellectual and technical procedures used to achieve knowledge. To be considered scientific knowledge, it is necessary to identify the steps for its verification, that is, to determine the method that made it possible to reach knowledge.

In terms of classification, this research fits as a qualitative research (carried out through interviews, observation and analysis), bibliographic (collected from data in different sources of bibliographic references) and explanatory (uses experimental procedures to explore the focus theme).

The method was structured according to the following steps: i) definition of the focus problem; ii) conducting bibliographic research; iii) preparation of an interview form; iv) selection of teaching professionals; v) conducting the interviews; vi) selection of elements and purchase of these from the 3D printer; vii) assembly of the 3D printer; viii) test of concepts of the 3D printer and, finally, ix) discussion of the results.

5 Case – Application

Once steps (i) to (iii) have been carried out, step (iv) was developed. In this stage, one of the project's researchers made contacts with professionals from public schools (course coordinators and teachers) in a city of the countryside of São Paulo state in Brazil. Thus, the selection of professionals was made (2 coordinators and 9 teachers).

Following, the researcher interviewed the professionals (step (v)), using the form previously prepared. In parallel, the other researchers of the project made the selection of the elements and purchased these elements for the 3D printer (step (vi)). The next step was the assembly of the 3D printer (vii), in order to proceed with the initial tests.

Among the additive manufacturing models, the layer by layer (LbL) printing model was adopted. This model takes the digital model as a reference and prints the piece layer by layer, until the product is completed. Considering the purpose of the project

and the parts that would be produced, it would not make sense to choose sintered printing models, for example.

The material chosen for the prints was the polymer known as PLA, which normally does not require the need for a hot bed for the execution of the process. That is, some polymers demand higher temperatures. Thus, in addition to melting in the extrusion process, it is also necessary to heat the platform that receives the printed object for better results.

As hardware, a Ramps board was used, exploring the arduino ecosystem, and nema 14 stepper motors. Such board provided input for temperature monitoring, so a thermometer was added to the equipment. In addition, for better precision in the printing process, an automatic leveling sensor has been added. A 12V 30A - 360W power supply was purchased to providing energy for the printer system. As software, Marlin firmware was used [60], an open source firmware developed for rapid prototyping applications. For 3D modeling, 3D builder, a free software from Microsoft, was used.

In the initial tests (step (viii)), there was a problem with the injector nozzle. Thus, it was necessary to include two more new steps in the 3D printer project: redesigning the nozzle and sending the nozzle file for the manufacture of the new nozzle. With the new nozzle, it was possible to complete the 3D printer's experimental testing stage. In figure 2, the 3D printer is shown, and in figure 3, the test results of the 3D printer are shown.

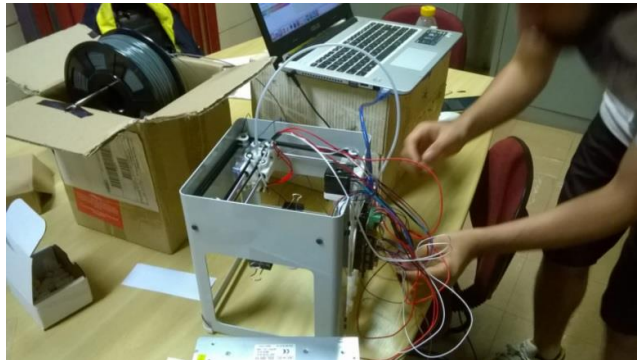


Fig. 2 – 3D printer



Fig. 3 – Printed piece

The next step (step (ix)) was the discussion of the results. That will be treated in the next item of this work.

6 Discussion

One of the aspects to consider was related to interviews with teaching professionals from public schools. A first aspect is that each category of professionals has on the application of new technologies. At first, a priori, the visions coincide: it is an innovation and can motivate students. In a second moment, the views are different: the coordinators are motivated to take the idea forward, but the teachers are afraid. But why do teachers have this view? Because they believe it will increase the workload, in the views addition to what they already have. However, there is another point, which they do not express: they do not master this new technology and, perhaps, have difficulties in learning (and this will require more workload, as some expressed outside the interview).

The coordinators, although motivated, raise a concern about how to conduct this idea within schools. The conditions of infrastructure and the financial resources of schools are major constraints on the idea's progress. Another consideration is bureaucracy, which involves the entire education system of public schools. Several instances are to be consulted (class council, school board, city education secretary, until the state education secretary is reached).

If, at some level of these instances, the idea is considered inappropriate for the moment, that idea will not go forward. That is what happened with this project because the justification was resource problems and the inappropriate moment for the idea.

About 3D printers, some considerations can be explored. A 3D printer can produce simple parts due to its technological restrictions. This fact was evident when it was necessary to redesign the print nozzle. However, for the project, the 3D printer met the needs, and the concept test was considered approved. Another question, regarding 3D printers, is the question of software. When we consider the application of 3D printers for teaching about the technology, the target users (the students) are interested in learning how to operate the technology. When we consider its application in other areas, where the 3D printer is a resource, the software and usability pose a significant challenge. As the technology is not thoroughly developed, the software requires somewhat advanced programming language knowledge, which is not widespread to the average public-school teacher. It is analogous to the beginning of the mainstream printers by Xerox, which were only ready to use by non-specialist after a sequence of incremental innovations [61].

7 Conclusion

Recalling the objective of the work which was to develop the work of applying 3D printers as an educational tool and strategy for improving the quality of teaching in Brazilian public schools. From the above, it is considered that the objective was partially met since the real implementation of the proposal was not possible.

The stages of development of the project were carried out until its part related to the 3D printer concept tests. The tests demonstrate the feasibility, at the technological level, as a strategy for introducing new technologies in basic education. However, there are variables external to the project and internal to the reality of the schools, which make the implementation of the project unfeasible at that time. Among the variables are the infrastructure, the financial resources and the bureaucracy existing in the school and in other instances, which make up the entire decision-making process.

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