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Innovation for Education on Internet of Things

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Abstract

The Internet of Things (IoT) and related objects are becoming more prevalent around the world with exponential growth for the next fifteen years. This evolution implies innovation in many fields of technology, whose core is in microelectronics. Indeed, IoT deals with all societal applications such as health, the environment, transport, energy and communications. Thus, connected objects involve many technological components: sensors and actuators, signal processing circuits, data transmission circuits and systems, energy recovery systems, which directly depend on the performance of microelectronics. To create new connected objects, innovation is the main driver. Innovation results from the combination of a multidisciplinary approach, links between disciplines and the necessary know-how of engineers and technicians. This paper deals with the orientation of pedagogy towards these objectives through the development of dedicated and innovative platforms in microelectronics. These platforms are developed by the French National Microelectronics Education Network (CNFM). After presenting the context of IoT and the evolution of microelectronics technologies, this article highlights the main components of connected objects applied to many societal applications. Each component of the objects requires specific microelectronic devices or circuits. Innovation appears in the nature of platforms, the multidisciplinary approach of training, the permanent links between disciplines, and the adaptation to new educational tools, mainly online. The results of the training on innovative platforms are presented and discussed.

Keywords: innovation, internet of things, microelectronics, nanotechnologies, education

1. Introduction

The Internet of Things (IoT) and related connected objects are becoming more prevalent around the world. About two hundred billion of these objects are expected to be in service in ten years, globally. This evolution implies innovation in many areas of technology, for which the core is in microelectronics. Indeed, the IoT concerns all societal applications such as health, environment, transport, energy, and communications [1-2]. Connected objects involve many technological components: sensors and actuators, signal processing circuits, data transmission circuits and systems, and energy harvesting systems [3]. All these specialties are directly dependent of the microelectronics capabilities. To create new connected objects, innovation is the main engine [4-5]. This innovating behavior results of the combination of the multidisciplinary approach, the links between disciplines and the necessary know-how of engineers and technicians [5-6]. This paper deals with the orientation of pedagogy towards these objectives through the development of dedicated and innovative platforms in the broader field of

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microelectronics. These platforms are developed by the French national network for education in microelectronics (CNFM) [7-8]. After presenting the context of IoT and the evolution of microelectronics technologies, this article highlights the main components of connected objects applied to many societal applications. Each element of the objects requires specific microelectronics devices or circuits. The innovation appears in the nature of the platforms, the multidisciplinary approach of the training, the permanent links between disciplines, and the adaptation to the new pedagogical tools, mainly online [6]. For the future technicians, engineers and PhD, the challenge is high and thus included in the strategy of the CNFM. The results of the training on innovative platforms are presented and discussed.

2. The Context of IoT: Connected Objects and Data Centers

The Internet of Things (IoT) and related connected objects are becoming more prevalent around the world. Internet of Things is supposed to include all the information stored in the data centers and all the connected objects that are transmitting information through the internet for remote control, security, but also production in the industry 4.0 [9]. Industry 4.0 represents the fourth industrial revolution in manufacturing and industry. Industry 4.0 is the current industrial transformation with automation, data exchanges, cloud, cyber-physical systems, robots, Big Data, AI, IoT and (semi-)autonomous industrial techniques to realize smart industry and manufacturing goals in the intersection of people, new technologies and innovation. This evolution will imply a huge development of connected objects and exchange of data through the internet (or equivalent network).

Taking into account this perspective, about two hundred billion of these connected objects are expected to be in service in ten years, globally [10], as shown in Fig. 1. This estimation seems much lower than the future real situation if we take into account the coming of 5G protocol for which witching and sensing will correspond to 100 billion of permanent units and tracking and tragging should correspond to 1 thousand billion of temporary units per year in short future [11-12].

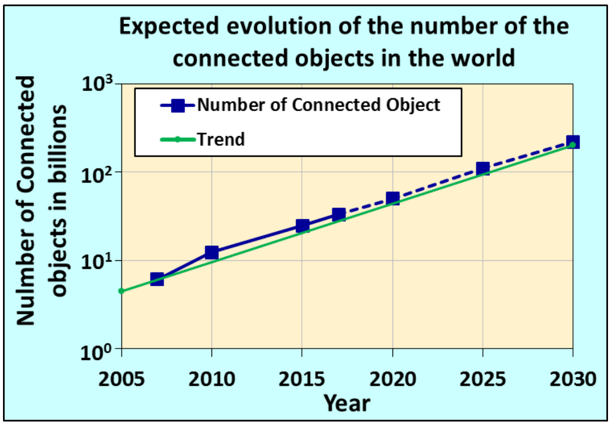

Fig. 1 Expected evolution of connected objects. The growth is exponential, similarly to Moore's Law. In 2025, about one hundred billions of things should be connected [10].

This evolution implies innovation in many areas of technology, for which the core is the microelectronics. Indeed, the IoT concerns all societal applications such as health, environment, transport, energy, and communications. Connected objects will be involved in these application domains. Their internal architecture involves many technological components: sensors and actuators, signal processing circuits, data transmission circuits and systems, and energy harvesting systems. Fig. 2 shows a simplified architecture of a connected object [10].

The analysis of the prospect of such a development leads to a huge problem of energy consumption which also exponentially increases with the introduction of new connected objects on the markets. The challenge for innovation will be to drastically reduce the consumption of basic electronic devices, to modify circuit architectures to reduce the instantaneous consumption of billions of transistors, to extend standby operation in order to minimize the power consumption of electronic systems. In addition, storing and processing data in large data centers require very high power consumption. Indeed, several predictions make aware of this problem of power. US researchers predict that electricity consumption will triple in the next five years, with an additional one billion people in developing countries [13]. The communications industry currently uses about 20% of the world's electricity, which hampers climate goals. The demand for energy-hungry data centers, which store digital data from billions of smartphones, tablets and devices connected to the Internet, continues to grow. In less than 10 years, more than 50% of the world's electricity will be used for communications if the current technology does not change.

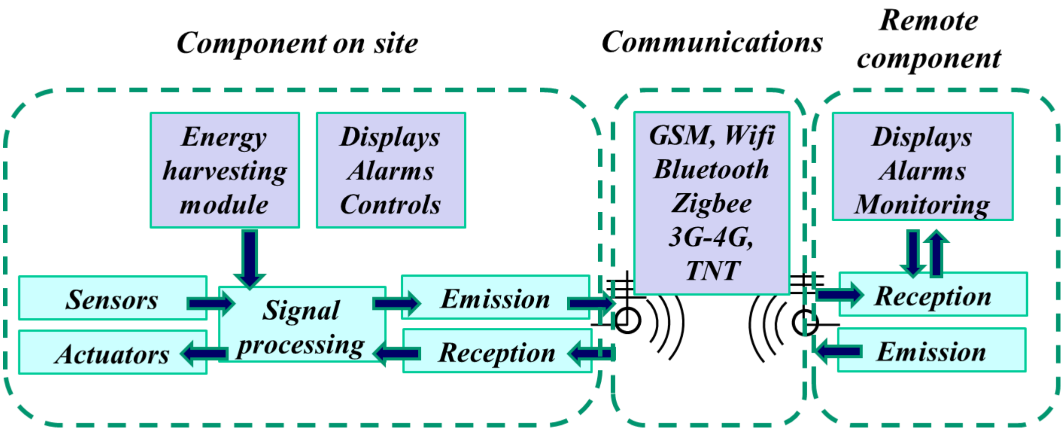

Fig. 2 Simplified architecture of a connected object. It is mainly composed of sensors and/or actuators, signal processing, emission and transmission module, visualization, alarms and controls, and energy harvesting when it is possible [10].

3. Evolution of the Microelectronics Technologies

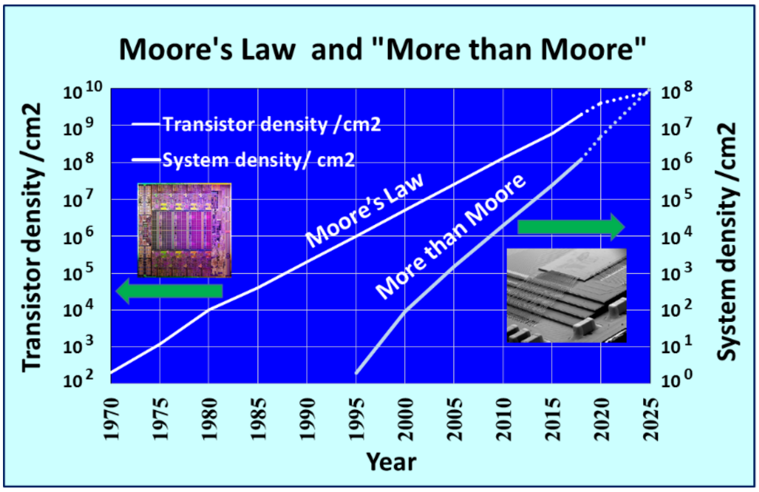

Fig. 3 Evolution of the integration. The Moore's law is expected to reach limits. However, thanks to new concepts, the integration is always going-up and becoming "More than Moore" with a similar exponential growth. (*After* M. Swamithan *et al*. [17]).

It is clear that the incredible growth of IoT and connected objects is a result of the constant evolution of the associated hardware through the integration of circuits and systems. For more than sixty years, integration has grown exponentially and follows the heuristic law proposed by G. Moore [14]. This increase in integration is mainly the result of the decrease in the size of the elementary semiconductor devices, mainly the transistors. The lateral size has gone from a few tens of microns to several nanometers in the most recent productions. Because the size of the elementary devices becomes close to the size of the atoms, the lateral decay in a plane (planar technology) has reached its limits if we keep the same architecture of the devices. That is why since the early 2000s, the growth of integration has resulted from new concepts based on i) the introduction of the third dimension in elementary devices, such as FinFet (Fin Field Effect Transistor [15]), ii) the stacking of many integrated circuits [16-17] iii) the development of heterogeneous technologies combining bulk silicon integration with thin film devices. The stacking leads to System-on-Chip (SOC) and System-in-Package (SIP) technologies that can gather in the same system several functions and several dies. Thus, the evolution of integration has found new growth with an exponential evolution similar to Moore's Law and called “More than Moore”, as shown Fig. 3. The system density reached today one million per square centimeter, each system containing thousands and thousands elementary devices.

4. New Tools for Education and Their Limitations

In such a context of digitalization and connection of the society, innovation also focuses on education. New teaching tools have been created for over twenty years. At first, texts and images were loaded on private servers. In the second period, the educational tools were accessible on the internet with new possibilities, for example by introducing animations and applets allowing several simulations [18]. Thanks to the huge development of data centers and internet communications, today these types of tools have improved considerably and their number has increased considerably. One can find many approaches to massive open online courses, MOOC [19], and more specifically several courses dedicated to microelectronics [20]. These online courses can contain many modules and interactive components as shown in Fig 4. This figure shows the classic content of these tools that are very practical for training students. These last can go further in the theoretical approach.

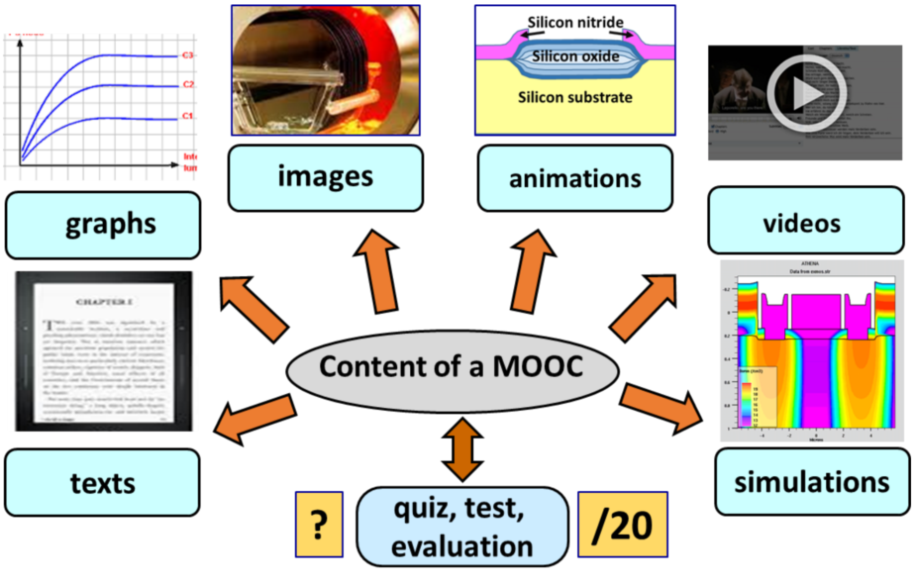

Fig. 4 Content of a massive open online course. Due to the improvement of the storage capacities, animations, video and simulations can be included in the applets of the MOOCs. (*After* O. Bonnaud *et al*. [3]).

Note that a first limitation to the use of these tools is maintenance. After a few years, the software that supports these tools change and it is more and more difficult to ensure the updates of the online course. In addition, the creation of such tools is a very long process and the updating of the content can also be very difficult if the designers who have contributed to their setting up are no longer present in the structure.

A second important limitation to these tools is the lack of experimental training that can provide the students with know-how. If it is possible to create specific classes devoted to the assimilation of knowledge, for example through problem-solving or flipped-classes [21], understanding and the acquisition of skills require experiential training and associate knowledge. However, in the context of engineering, such a policy is almost impossible to apply by a single academic institution.

5. Know-How in the Frame of Mutualized Platforms

As mentioned above, the orientation of pedagogy towards these objectives requires the development of dedicated and innovative microelectronics platforms. But in microelectronics, the practice requires sophisticated equipment such as workstations capable of receiving complex and heavy software for CAD, characterization benches capable of analyzing components and devices at the nanoscale, cleanrooms providing equipment for manufacturing, components and circuits in conditions similar to foundries but with lower requirements. All of this equipment is very expensive, representing hundreds of millions of US dollars in total, and the only realistic solution is to share the investments and operations between several institutions. Thus, twelve common centres were gradually created in the 1980s in France spread throughout the territory and mainly located in areas where activities carried out by industries and academic institutions were already developed. These platforms were created and financially supported, at least partially, by the National Microelectronics Education Network (CNFM) with the aim of minimizing duplication. In fact, apart from the common basic know-how, the centres are specialized in terms of technologies (silicon integrated circuits, nanotechnologies, thin film technologies, organic technology, etc.), circuit nature (analogue, digital, HF, high power, displays, etc.), and fields of application (health, biology, automotive, etc.). Fig. 5 shows the distribution on the territory of the twelve centres of the French national network, already detailed in a previous article [7]. In addition to the twelve academic partners, two industrial organizations are partners in this network [22-23]. These two industrial structures represent the majority of companies that are working in France in the field of electronics, microelectronics, and electrical engineering. Their participation in the network is important to define the strategy to be adopted in order to best meet their needs. Today, the twelve centres manage more than eighty platforms, including seven cleanrooms. The Montpellier centre is in charge of the purchasing and the distribution of all microelectronics CAD software licenses including CADENCE, Mentor Graphics, Synopsis, SILVACO, ALTERA, XILINKS, and many others. This centre is also in charge of the national platform for testing mixed integrated circuits. Indeed, the centre of Montpellier manages a national equipment allowing a test remote from all the other centres. 89 academic institutions and 60 laboratories are users of the software and this platform. But all these tools are in permanent evolution which justifies a permanent update of the software and the equipment.

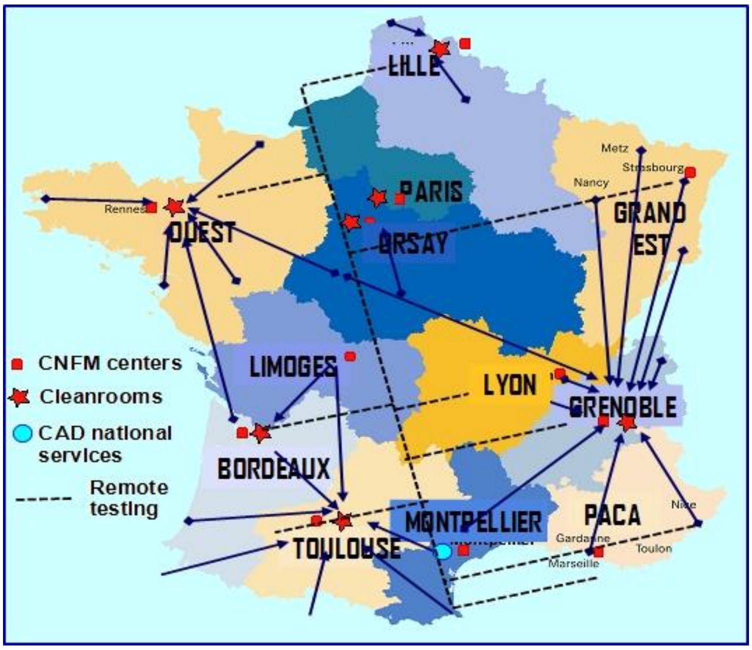

Fig. 5 CNFM: French national network. The twelve centres are spread all over the French territory. (*After* O. Bonnaud *et al*. [3]). The CAD tools are managed by the “National Service” insured by the CNFM centre of Montpellier.

The consequence is that the French network has an incentive policy towards the partners, leading them to create new platforms, new practices and new software every year. This policy was strengthened in 2012 thanks to a national program dedicated to innovative education launched by the Office of the Commissioner for Large Investments for the Future [24]. The GIP-CNFM responded to the call and successfully completed the FINMINA project for innovative training in microelectronics and nanotechnology [25]. As part of this project, some 60 platforms have been created or updated which have been included in the menu of microelectronics and nanotechnology centres.

6. Innovative Training on Platforms

The themes of the innovative platforms cover a broad spectrum. We focus on a selection of recent realizations that preferentially relate to connected objects and are open to initial training. All these subjects are intended to give students some know-how. Fig. 6 shows several examples of end objects that have been designed, manufactured, and characterized by students on the platforms of different network centers. The top three images yield results on the design of a Fully Programmable Gate Array (FPGA) circuit, a digital circuit, and a digital-to-analog converter. The four middle images show the design and electrical characterizations after the fabrication of an RF transmitter circuit, a sensor on a flexible substrate and a connected building energy controller. The three lower images show a three-dimensional sensor associated with its electronics in "plastronic" technology, and a connected drone. The most complex objects are designed and produced by groups of students in the frame of projects or internships. They are all included in the "innovative training", that is to say, they have been introduced gradually since 2011.

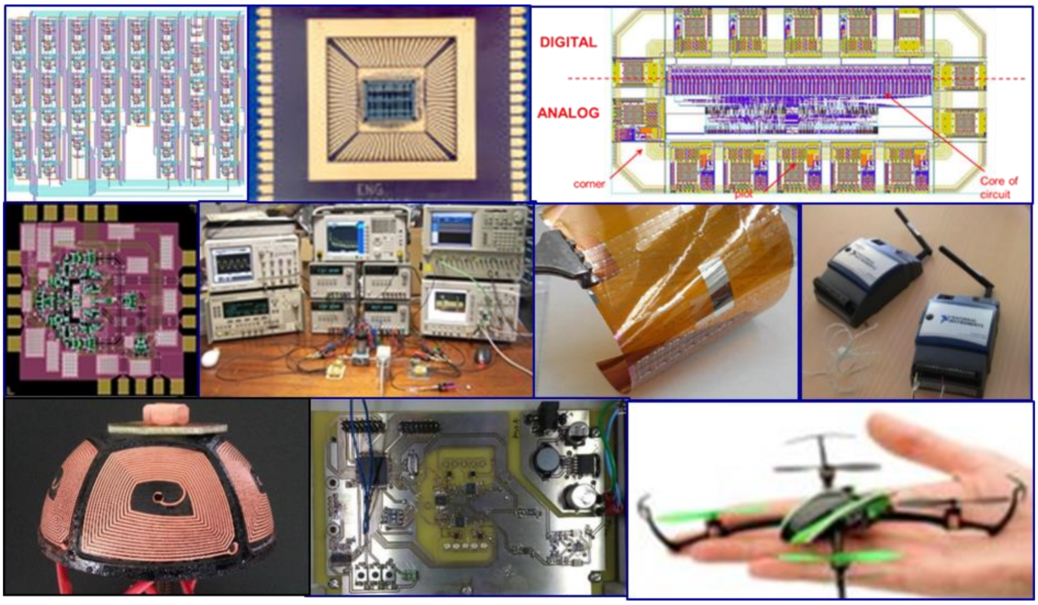

Fig. 6 Realization by students of different circuits and systems that can be involved in the connected objects. They can involve different technologies, from silicon integrated circuits to flexible and thin film technologies.

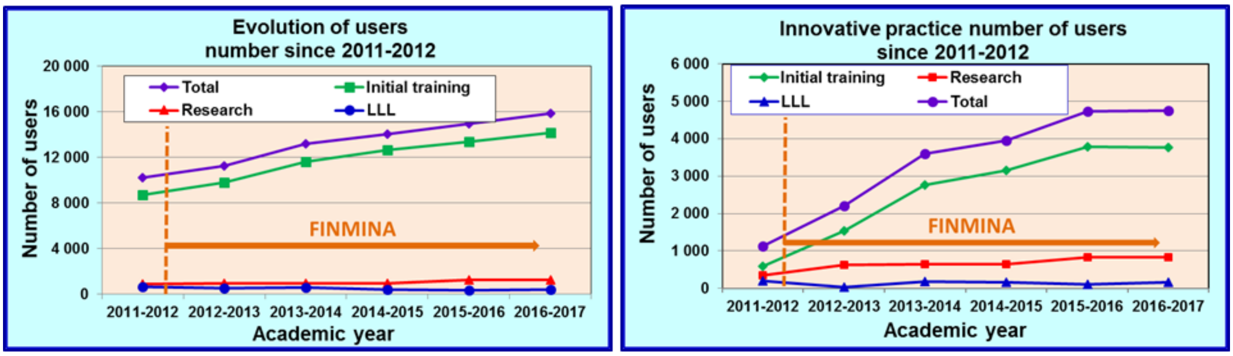

Fig. 7 Left - Number of users on French platforms. This number has increased in recent years and reaches 16,000 in 2017. Right - Number of users of innovative practices, which has increased rapidly since the starting of FINMINA project.

Many other examples could be presented but this is not the purpose of this paper. Information on the platforms and their use by students can be obtained on the network's website [7]. For a multidisciplinary purpose adapted to connected objects, practical works on sensors and actuators are also proposed to students [26]. They all give experience and bring their know-how to the students. In order to show the effectiveness of the network, we establish each year a survey on practical training. We have plotted the evolution of the number of users and of the number of hours in the network and the part of the innovative training in Fig. 7 and 8. Fig. 7 shows the growth of the number of students mainly in initial training. The innovative practice has led to a significant increase in the number of students since the start of the FINMINA program. It is the result of the opening of the subjects proposed to other disciplines, more particularly to health, biology and mechanics.

Fig. 8 shows the number of hours per year. The total number of hours of initial training is almost constant while the innovative part has significantly increased (right). Indeed, the volume of practical training per student has followed a very bad evolution for several years, the universities considering that the cost is high, they try to reduce the practical training in the courses. The average time spent on the platforms has therefore decreased. However, more students are users which maintains the total activity.

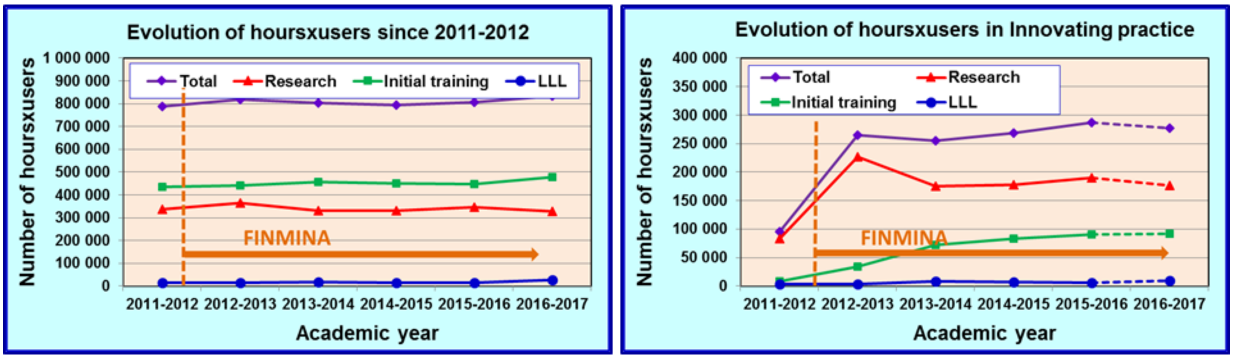

Fig. 8 Left – Evolution of the number of hours spent on the French platforms. Right – the total number of initial training is almost constant while the innovative part has significantly increased since the beginning of the FINMINA project.

7. Conclusion and Discussion

The know-how remains very important in science and engineering and more particularly in microelectronics which is at the heart of the Internet of Things, but the cost is higher and higher. The current strategy is to share technology platforms dedicated to practical training. This strategy was applied by the French network CNFM which created twelve inter-university centers. These centers host approximately 14,000 undergraduate students each year on more than 80 technology platforms. To maintain the level of know-how that students can acquire and meet the needs of society [27], platforms are continually updated as part of an innovative strategy. Innovation appears in the nature of the platforms, the multidisciplinary approach of training and the adaptation to new pedagogical tools. This approach has proved its interest through the growing number of users. In the field of microelectronics, the danger comes from the permanent growth of investments and the new tendency of several universities and institutions to reduce the volume of practical training even if the online courses can't make the same contribution to the acquisition of skills. Practice is a necessary complement to theoretical knowledge. The national network policy needs to be strengthened to maintain the quality of training and skills of graduate students who can contribute to the development of the Internet of Things.

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