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# The core components of education 4.0 in higher education: Three case studies in engineering education

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A R T I C L E I N F O

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A B S T R A C T

Technological progress and its rapid evolution have positively affected the industrial sector and different productive/service sectors. One of the service-sectors that have benefited the most has been Education. In this sector, the implementation of current and emerging technologies combined with innovative pedagogical procedures and best practices is known as Education 4.0, which, in this paper, is described and mapped according to the well-known periods of the four industrial revolutions and related to higher education. Likewise, four core components of Education 4.0 to be used as a reference for the design of new projects in educational innovation are proposed (i) Competencies, (ii) Learning Methods, (iii) Information and Communication Technologies, and (iv) Infrastructure. Finally, three case studies applied to Engineering Education illustrate how the proposed components are considered in educational programs' designs.

## I. Introduction

In recent years, the term "Education 4.0" has been assigned high relevance by different authors who have conceptualized it according to the well-known four industrial revolutions periods. Accordingly, how the evolution of technologies has influenced the education sector through time has been analyzed. Hence, pedagogy, teaching philosophies, educational models, information sources, learning methods, and students' and educators' roles have been included in the conceptualizations. Nowadays, it is observed that methodologies, practices, and activities seek to personalize knowledge generation and information transfer processes and make them more efficient, accessible, and flexible. Therefore, currently, educational innovation projects have emerged to achieve current educational challenges [1].

Consequently, educational institutions, including education departments, research centers, and universities, support and encourage educators and researchers to lead initiatives and projects in educational innovation by designing and developing new practices, methodologies, and applied technologies [2]. It has been observed that these initiatives and projects must align with the needs and requirements of educational institutions to respond to current social contexts, considering technological megatrends as

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drivers to achieve innovative solutions [3]. These innovative solutions will improve teaching-learning processes and management processes and create desirable environments for essential pedagogical procedures.

Thus, these innovative solutions have been implemented on a large scale for new teaching-learning programs in higher education, including continuing education and lifelong learning programs. New distance learning programs have also emerged, mainly taking advantage of connectivity, digitalization, and virtualization platforms [4]. Nevertheless, there is a lack of information, design methodologies and evaluation mechanisms that allow designers and educators to use technologies and emerging pedagogy procedures to provide the right innovative solutions, especially for engineering programs. So, it is necessary to build reference frameworks to guide designers during the design and implementation processes.

In this paper, the authors redefine Education 4.0 to align with this sector's current needs and challenges. The newly proposed concept is based on the current vision of Education 4.0 in higher education seeking to graduate a new generation of highly competitive professionals capable of applying the right physical and digital resources to provide innovative solutions to current and future societal challenges. Different authors consider implementing emerging technologies, current social contexts, and innovative pedagogical procedures as part of this concept.

In this work, the authors seek to answer three main research questions (i) What are the core components that shape Education 4.0 to achieve its current vision in higher education? (ii) How do the defined components influence the generation of new programs in engineering education? (iii) How do the resulting educational innovations impact the development of required critical competencies in today's engineering students?

To answer these questions, the authors propose four core components to shape the proposed concept of Education 4.0. (i) Competencies (training and developing desirable competencies in today's students), (ii) Learning Methods (incorporation of new learning methods), (iii) Information and Communication Technologies (ICTs) (implementation of current and emerging ICTs), and (iv) Infrastructure (use of innovative infrastructure to improve teaching-learning processes). These components can comprise a reference framework during the design of new educational innovation projects. Consequently, insights for developing new content, pedagogical procedures and new projects in educational innovation can result.

The remainder of this paper is structured as follows: Section 2 presents a review of the transition from Education 1.0 to Education 4.0. Section 3 presents the concept of Education 4.0 in higher education and describes each of the proposed core components shaping Education 4.0. Subsequently, Section 4 provides three case studies that illustrate implementations of the Education 4.0 concept in engineering education. Finally, Section 5 offers conclusions from the main findings of this work with suggestions for future research.

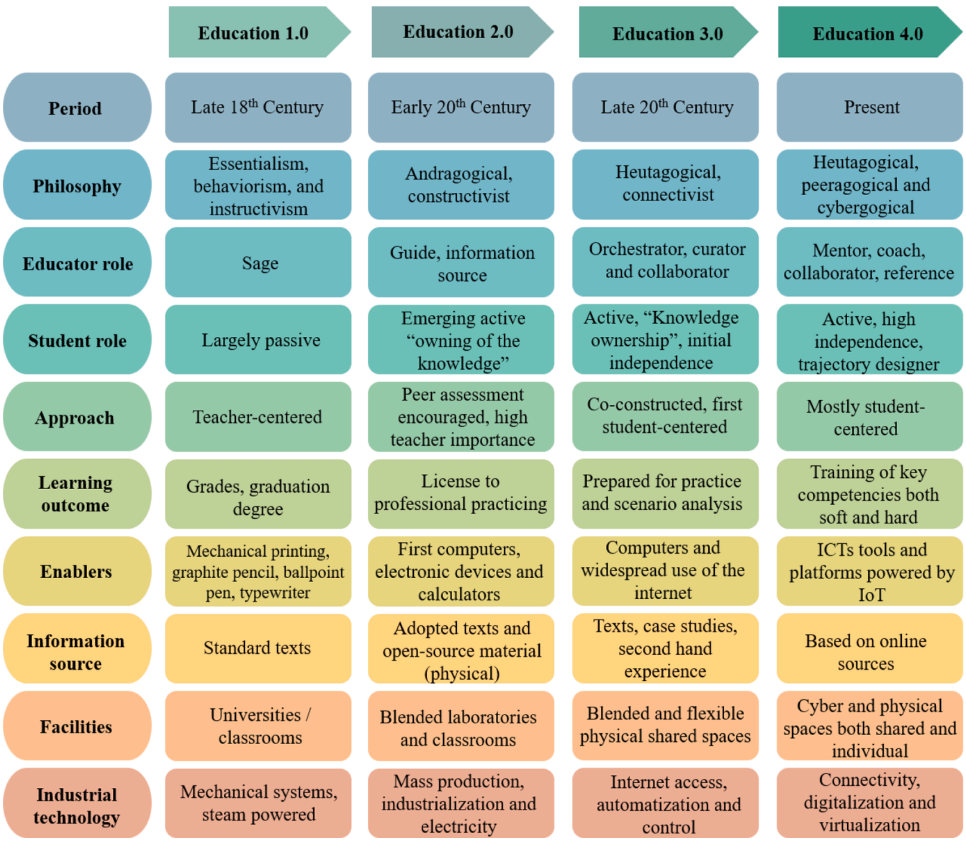


**Fig. 1.** Summary of the transition from Education 1.0 to Education 4.0.

## 2. The transition from education 1.0 to education 4.0

After the first industrial revolution that occurred at the end of the 18th century, the education sector proliferated, beginning the period of Education 1.0. It was characterized by systems mechanization that resulted in the emergence of enabling technologies for education such as the paper-making machine, mechanical printing, the graphite pencil, the ballpoint pen, and the typewriter. This period stood out due to educational philosophies based on essentialism, behaviorism, and instructivism. The educator was seen as a sage, and the student had a mostly passive role. Therefore, in the Education 1.0 period, the teacher was the center of education, tasked with determining and disseminating the essential information that the students needed.

Education 2.0 coincided with the second industrial revolution in the early 20th century, characterized by mass production, industrialization, and electricity. In this period, the primary information sources were open-source materials from libraries. The technological advancement in Education 2.0 brought relevant contributions to this sector, and the first electronic devices used in education, such as printers, calculators, and computers, emerged. The educational philosophies in this period were mainly andragogical and constructivist. The teacher's role changed from a sage to a reference and information source to help develop the tools for professional implementation, and the student's role continued to be passive. Nevertheless, an active role for students began to emerge, where students became "owners of the knowledge." The learning approach was also teacher-centered, but peer assessment was encouraged, with the teacher still being fundamental. Also, in this period, practices such as correspondence education and broadcast education appeared.

Education 3.0 emerged in the third industrial revolution at the end of the 20th century and revolved mainly around computerization, automation, and control. In this new communication era, the student and teacher began their transitions to a vision in which they no longer needed to participate in a synchronous session for learning to happen. The teaching-learning processes were supported by multiple resources such as multimedia, online tools, and virtual laboratories. This teaching-learning approach was more heutagogical and connectivist. Each teacher was considered an orchestrator, curator, and collaborator, and the students were empowered to build their knowledge.

Currently, the fourth industrial revolution and the technologies and innovative pedagogical procedures and best practices that characterize this period comprise what is known as Education 4.0. The diagram in Figure 1 compiles the relevant concepts of the higher education transition from Education 1.0 to the current industrial and educational paradigm of Education 4.0. The infographic's sources to define the structure are the works of various authors whose research elements were included in this section [4, 5].

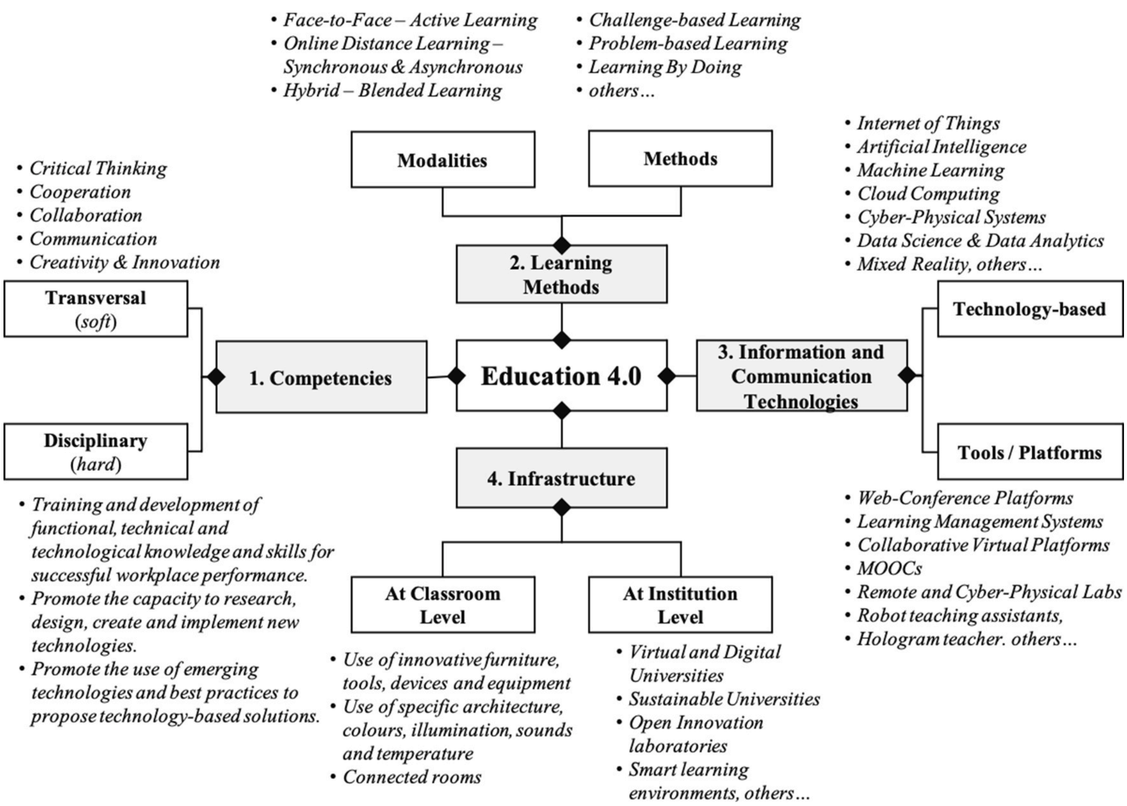


**Fig. 2.** The four core components of Education 4.0 in higher education used as a reference framework

## 3. The concept of education 4.0 in higher education

Incorporating the Education 4.0 concept has allowed educators and students to leverage modern infrastructure and emerging technologies to improve higher education pedagogical procedures. In this regard, pedagogical approaches are also evolving and reorienting their paradigms towards innovation in their training processes to meet the needs of a continually changing technological society. Hence, it is considered that knowledge generation in Education 4.0 transcends pedagogy and andragogy towards an approach that combines *heutagogy, peeragogy,* and *cybergogy*. Through heutagogy, Education 4.0 promotes self-learning based on humanist and constructivist principles centered on the student for learning and teaching. Self-reflection and metacognition, or the understanding of one's learning process, are encouraged. Peeragogy is an old concept that has been rethought with the advent of Education 4.0; it alludes to the foundation of collaborative learning. It refers to the set of teaching techniques that promote learning among peers [6]. Also, cybergogy has come about due to technological advances and the internet evolution that have favored educational offerings. W. Daud et al. define cybergogy as learning strategies promoted by ICTs that offer learning experiences that go beyond the limits of time and space [7].

These technological advances, combined with these approaches, enable facing current needs and challenges that are mainly related to creating programs and environments that incorporate these procedures. To achieve this, educators must create enablers for Education 4.0. These must consider emerging technologies and new learning methods and requirements of current regional and global social dynamics to ensure their proper implementations. With these advancements, students can be immersed in appropriate learning environments that will allow them to improve their learning processes and the training and development of critical competencies, allowing students to be prepared for future scenarios. Consequently, innovative educational models and enablers that will enable institutions to achieve the vision of Education 4.0 must be designed and implemented.

Therefore, in this paper, the authors redefine Education 4.0 to summarize different approaches to understand better how this concept can be used as a reference framework in designing new projects in educational innovation. The proposed concept of Education 4.0 in higher education is:

*Education 4.0 is the current period in which Higher Education institutions apply new learning methods, innovative didactic and management tools, and smart and sustainable infrastructure mainly complemented by new and emerging ICTs to improve knowledge generation and information transfer processes. Combining these resources during teaching-learning processes will support the training and development of desirable critical competencies in today's students.*

In this paper, the authors propose four core components that shape the proposed concept of Education 4.0. These components are (i) *Competencies* (training and development of desirable critical competencies in today's students), (ii) *Learning Methods* (incorporation of new learning methods), (iii) *Information and Communication Technologies (ICTs)* (implementation of current and emerging ICTs), and (iv) *Infrastructure* (use of innovative facilities, services, and systems to improve learning processes). Figure 2 summarizes the concept of Education 4.0 and its four core components. This figure also shows relevant examples of implementations of the proposed components.

### 3.1. Competencies: Training and development of desirable critical competencies in today's students

Since the 1990s, competency-based education has had the most significant impact on higher education worldwide. The development of professional competencies in universities, including transversal (soft) and disciplinary (hard) ones, posed the challenge of designing educational models enabling students to face situations, challenges or problems that require the development of knowledge and efficient know-how. The higher educational institutions use this notion to respond to knowing what is useful for learning at the university; by learning and developing the most general competencies, students can apply them in their personal, professional and social lives [8].

In this sense, some organizations and academic institutions have defined critical competencies to be promoted in higher education [9]. Hence, new learning methods, activities and tools have emerged from training and developing these competencies. In this work, a set of transversal and disciplinary competencies are defined as critical competencies because they encompass personal, emotional, social, and intellectual capabilities and the associated behavior and knowledge that today's students must apply in professional life. These competencies are described below:

*Transversal competencies.* In the period of Education 4.0, five key transversal competencies have been identified as core competencies to be fostered in higher education: (i) Critical Thinking, which encourages students' immersion in real problems through the implementation of different problem-solving techniques. ii) Cooperation, through activities that promote group members' individual participation by dividing responsibilities among the participants; therefore, each participant is responsible for solving a part of a complex problem or project. (iii) Collaboration, through teamwork activities; then, the students must demonstrate that they can interact and work on collaborative projects [10]. (iv) Communication, through activities that foster students to effectively express their ideas in oral, graphic, or written ways, even using media or any technological resources. Thus, the students can enhance their communication skills and apply them in complex communication behavior such as negotiations, pitches, and project explanations. Finally, (v) Creativity and Innovation through activities that encourage students to design, develop, and research to materialize creative and innovative problem solutions. Consequently, the proposal of solutions to improve any service, process, system, and practices to maximize resource use is promoted by developing these competencies.

*Disciplinary Competencies*. These competencies are associated with specific technical knowledge and task-oriented skills to be applied in a specific field. In Education 4.0, the training and development of disciplinary competencies are more related to achieving technological systems' development and implementation. These competencies have three aspects: (i) the training and development of functional, technical, and technological knowledge and successful workplace performance skills. (ii) the capacity to research, design, create and implement new technologies. (iii) the use of emerging technologies and best practices to propose technology-based solutions [11].

### 3.2. Learning methods: Incorporation of new learning methods

In Education 4.0, traditional learning methods must be adapted to include strategies, technologies, and activities that allow students to access appropriate learning and training programs. Since Education 4.0 seeks to provide more efficient, accessible, and flexible educational programs, new teaching-learning methods emerge that consider the use of technologies and proven principles, strategies, styles, and pedagogical procedures that are increasingly used in higher education. Thanks to these opportunities, new teaching-learning methods are delivered in different modalities to optimize knowledge generation and information transfer and resources. Consequently, new and innovative face-to-face, distance, and hybrid learning programs have appeared. For example, the emergence of distance education programs using mainly the internet of things (IoT) connectivity has significantly impacted the rise of lifelong learning programs and alternative credentialing programs.

Nevertheless, significant challenges continue to be faced in this sector, primarily related to providing new methods for specialized training in the current world where complex engineering problems are no longer confined to an individual discipline of science or engineering [12]. Hence, incorporating these methods must be considered in new programs and innovative educational projects. In this section, two main features are proposed to be considered as part of these processes (i) the learning delivery modality and (ii) the learning method to be used:

*Learning delivery modalities*. In this period, how teaching-learning processes are delivered has assumed great relevance since technological advances have allowed educational institutions to deliver teaching-learning programs in different formats. Higher education courses and programs are adopted and combined with different delivery modalities to provide more accessible and flexible programs and provide relevant and personalized content. Therefore, three often used learning-delivery modalities in the period of Education 4.0 can be highlighted: (i) Face-to-Face learning is based mainly on *Active Learning.* (ii) Online distance learning leverages current technological platforms to carry out remote processes applying digitalization, virtualization and connectivity through synchronous and asynchronous activities that immerse students in flexible-digital models. (iii) Hybrid learning, through techniques like blended learning or flipped classroom, optimizes learning processes and resources.

*Learning Methods.* These methods also involve principles, strategies, styles, and pedagogical procedures for teaching-learning processes in different modalities. In Education 4.0, new learning methods are emerging to respond to the current need to build a generation of highly competent professionals. Therefore, new programs adapt current student-centered or learner-centered models where students actively participate in the learning processes and apply current and emerging technologies to enhance the teaching-learning processes. Consequently, innovative learning methods based on collaborative and cooperative activities emerge along with pedagogical approaches such as challenge-based learning, problem-based learning, learning-by-doing, and gamification-based learning.

### 3.3. Information and communication technologies: Implementation of current and emerging ICTs

The use of ICTs in higher education has become critical as educational systems change from a traditional to a student-centered model, allowing students to develop competencies to adapt to these changes [13]. ICT is a collection of technological resources that facilitates the access, distribution, and collection of information. ICTs comprise an indispensable tool that contributes to the new ways of teaching, not just by its use but also in how it enables students and educators to work collaboratively to enhance the learning process by accessing knowledge at any moment, sometimes remotely. Nevertheless, incorporating ICTs in higher education is not innovation per se; instead, its purpose and the value it adds when combined with teaching-learning methods are innovative. It started with the interaction of tools derived from the increasing use of Internet connectivity services.

In this work, the ICT component of Education 4.0 can be considered in two ways: (i) *Technology-based,* incorporating working principles of technologies and techniques to provide technology-based solutions, and (ii) *Tools and Platforms,* which are emerging technology-based solutions that combine different technologies for educational and management purposes.

*Technology-based*. Current and emerging technologies provide robust capacities and capabilities for this sector's tools and platforms. Therefore, many technological implementations that support pedagogical procedures leverage modern techniques powered by the IoT, such as Artificial Intelligence and Machine Learning, High Data Processing applying Data Science, Data Analytics and Cloud Computing [14], and Virtual Image Processing for virtual and experiential environments [15]. Hence, the evolution of these technologies has improved current tools and platforms and resulted in the constant emergence of innovative implementations.

*Tools and Platforms*. Implementing the mentioned techniques and working principles has garnered robust tools and platforms that have considerably improved teaching-learning processes in many aspects, for example, web-based technologies processing enormous data amounts and offering services such as email, blogs, wikis, and, more recently, the virtual learning environments [16]. The ICTs, due to their capacities and capabilities, open up new possibilities for innovation and improvement of formal teaching and learning processes. Also, learning programs for virtual classrooms and collaborative platforms are emerging, complementary or independent of traditional education modalities [17]. The learning platforms offer synchronous online sessions to support student learning through web conference technologies (e.g., ZOOM, Meets, Webex, M-Teams) that incorporate voice, text, images, and video, allowing students to participate in the sessions [18] actively. In a complementary way, Learning Management Systems (LMSs) have evolved to provide learning spaces that allow educators and students to work synchronously or asynchronously, or in a hybrid combining both, facilitating collaborative learning [19]. Some of the most used LMSs are Blackboard, CANVAS, Google Classroom, Moodle, Sakai, and Edmondo.

Other relevant implementations of tools and platforms occur in mixed reality laboratories [20], educational robotics [21], web-based learning, M-learning, intelligent tutoring systems, robot teaching assistants [22], virtual and experiential environments [15], and Hologram-Teacher formats [23], among others.

### 3.4. Infrastructure: Use of innovative infrastructure to improve learning processes

Learning environments in Education 4.0 are supported by suitable infrastructures for learning and teaching practices that accommodate students' learning needs and support current educational challenges related to teaching and management activities. Consequently, innovative virtual and physical infrastructures are emerging in response to current needs and challenges. There are two levels proposed to describe the currently used infrastructure in higher education (i) at the classroom level and (ii) at the institutional level:

*At the Classroom Level.* This level mainly considers adequately equipping the classroom, so innovative furniture, connected tools, and other educational and didactic resources are considered. Another relevant issue to ponder at the classroom level is the design of learning environments since it is observed that specific design characteristics positively influence how students learn. Therefore, studies in pedagogy and psychology have shown that learning environments such as classrooms or rooms such as collaborative spaces, learning commons, and libraries can be adapted with specific architecture, colors, illumination, sounds and temperature to improve learning [24]. Also, it is noted that these spaces can include technologies that permit interaction with virtual and digital resources such as virtual and augmented reality and hologram systems. Besides these, learning spaces are also assessed for recreation, collaboration, and comfort. The *home as a classroom* falls into this category: current students, educators, and staff are conditioning their houses and adopting specific infrastructures to carry out academic activities. These infrastructures include access to internet services, equipment connected to the network, and, sometimes, even customized furniture.

*At the Institution Level.* This level contemplates the use of facilities, services and systems that are part of an educational institution. This infrastructure is considered not only for pedagogical procedures but also for management and service processes. Today, institutions provide spaces for better learning environments and seek spaces and best practices for the well-being of students, teachers, and employees in their institutions. These considerations involve not only students and educators but also collaborators within an institution. Consequently, the infrastructure in an educational institution also includes recreation, comfort, sustainability, and accessibility. In 2020, as a result of the worldwide coronavirus health emergency, most educational institutions quickly had to adopt virtual and digital infrastructures to strengthen their capacities and capabilities to guarantee academic continuity remotely. These infrastructures include ICT platforms that employ connectivity/digitalization/virtuality capabilities to support virtual classrooms with web-conferencing and LMS. Many services such as online libraries, instant messaging systems, and remote laboratories became enabled and widely used.

## 4. Education 4.0: Three case studies in higher education

### 4.1. Case study: Use of a decision-making laboratory to support students' visual analysis to solve a transportation problem in Mexico City

In this case study, a teaching-learning program used a Decision-Making Laboratory combined with other core components of

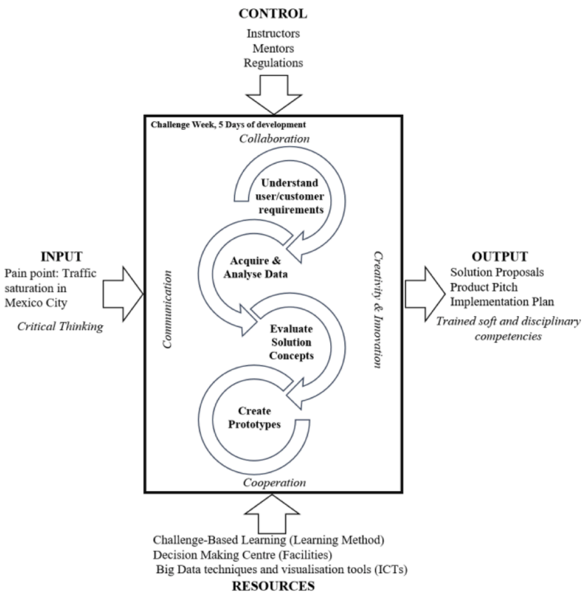


**Fig. 3.** The Learning dynamic and components of the Challenge Week

Education 4.0 to support the training of highly competent professionals.

ProblemA big concern among students is if they will be capable of facing the problems they need to solve in their professional lives, questioning if traditional classes would provide them the required knowledge and abilities to be professionally competent as the industry evolves.

Proposed solution A challenge-based learning program was designed with a Decision-Making Laboratory as the principal component of its infrastructure. The designed program was named "Challenge Week." It was designed by Tecnologico de Monterrey, collaborating with Mexican companies as training partners. They defined a set of challenges based on industry demands. The students had to work full time for an entire week (Monday to Friday) to receive the information about a real-world problem, analyze the situation, and obtain the proper complementary training to propose a solution to the challenge presented to them. The students' main objective was to apply adequate methods and instruments to collect and analyze the data and information and propose the right solutions.

Methodology This case study research methodology used a qualitative approach. The program design presented the students with an academic challenge to propose solutions to a real-world problem. Its implementation was carried out using a Decision-Making Laboratory as the infrastructure. An evaluation was carried out to know the level of competencies acquired. The students' perceptions of the program were surveyed by a questionnaire. The process is described in detail below.

The "Challenge Week" was held during the fall semester in 2016. In the last third of their curriculum, computer science students worked on a real social problem about traffic saturation in Mexico City. The data was provided by the Mexican Company "Sin Tráfico," the Mexican Institute of Statistics and Geography (INEGI), and a public transportation department of the government that provided data produced by GPS technology. The requirement was to generate various alternatives for effective decision-making to solve the mobility problem in traffic-saturated areas in Mexico City. Using the information provided and following a methodology established for the Decision-Making Laboratory, the students had to develop a solution proposal.

Figure 3 shows a diagram of the methodology. In the *Understand, user/customer requirements* phase, the students identified the objectives, scope, solution perspective, and restrictions. Students also received complementary training during this phase, focused on the traffic-saturated Santa Fe zone of Mexico City, systemized transportation, GPS technology, and visualization information background. During the *Acquire & Analyse Data* phase, students supplemented the information searching in external sources, worked on solution alternatives, and identified KPIs to measure the solution proposal quantitatively and qualitatively. In the *Evaluate Solution Concepts* phase, the students focused on the most viable solution and created a strategic plan, including the costs, development time, and implementation risks. In the *Create Prototype* phase, the students presented the solution to Mexico City's governmental authorities, who analyzed the deliverable and gave the students feedback.

Results & Discussion Four solutions were proposed, which included (i) government regulations, (ii) implementation of adequate infrastructure and rental of bicycles and motorcycles to reduce private cars' use, (iii) creation of an exclusive transportation route only to be used by workers having jobs in the zone, (iv) promotion of ecological transport such as scooters available at the exit of public transport, ready to be used by passengers to go to their final destinations. Finally, a quantitative evaluation was applied to assess the overall performance of the students.

The learning outcome results were satisfactory, with an overall average of 92.875 on a 100-scale final presentation and 97.5 for final documentation. The results in the experiment and the quantitative evaluation proved that student performance ranged from good to excellent. These kinds of challenges contribute to improving teamwork and elaborating complex solutions. "Challenge Week" was

**Table 1**
Challenge Week summary table showing the core components of Education 4.0

| | | | | |
|---|---|---|---|---|
| **Alternative Credential:** The Challenge Week | | | | |
| **University:** Tecnológico de Monterrey, Mexico | | | | |
| **Class Format:** Face-to-Face | | | | |
| **Language:** Spanish | | | | |
| **Participants:** 21 undergraduate students, teams of 4-5 students | | | | |
| **Duration:** 1 week, 40 hours | | | | |
| **Experiment:** Mixed-method, quantitative approach with disciplinary and transversal rubrics | | | | |
| | **Core components of Education 4.0** | | | |
| **Modules** | **1. Competencies** | **2. Learning Methods** | **3. ICTs** | **4. Infrastructure** |
| **1. Understand user/customer requirements**: Students were provided with the challenge problem, related information, and additional lectures | *Soft*: Critical Thinking. *Hard*: Disciplinary Training, Self-learning | Challenge Based Learning, Active Learning, Mentoring | Open Access databases | Collaborative Rooms |
| **2. Acquire & Analyse Data**: Search for external sources, consider solution alternatives, and define KPIs | *Soft*: Creativity and Innovation. *Hard*: Research on external sources; data sciences Analyses | Challenge Based Learning, Active Learning | LMS | Smart classroom, Decision-Making Laboratory |
| **3. Evaluate solution concepts**: Solution proposal with an implementation plan, including costs, risks, and development time | *Soft*: Collaboration and Critical Thinking. *Hard*: Project Management Skills | Collaborative and cooperative projects, Challenge Based Learning, Active Learning | Visualization and simulation tools | Decision-Making Laboratory |
| **4. Create prototypes**: Presentation of the solution proposal to Mexico City's governmental authorities | *Soft*: Communication. *Hard*: Project Pitch, Use of new infrastructure (Decision-Making Laboratory) | Challenge Based Learning, Active Learning, Mentoring | Visualization tools | Decision-Making Laboratory |

supported by a decision-making laboratory as a facility that promoted collaboration, cooperation, communication, creativity, and innovation through active, challenge-based learning activities typical in the Education 4.0 framework. Table 1 provides a summary of this case study.

### 4.2. Case study: Encouraging entrepreneurship in higher education through the sensing, smart and sustainable enterprise creation bootcamp

Today, universities are excellent drivers of innovation and technology entrepreneurship through the implementation of new teaching-learning programs. Novel programs and alternative credentialing have emerged to provide proper training of the essential competencies necessary in today's entrepreneurs' profiles. Thus, it is expected that students can improve decision-making processes, implement better operational strategies, and accelerate creating new technology-based products/services/processes and enterprises. In this case study, students designed and implemented the Sensing, Smart and Sustainable ($S^3$) Enterprise Creation Bootcamp in a hybrid learning modality, using as a reference the four core components of Education 4.0.

**Problem:** The Government of Mexico City, through the Office of Education, Science, Technology, and Innovation, is working on providing new initiatives that promote innovation and entrepreneurial culture in society, having observed that innovation and entrepreneurship are excellent boosters of better solutions, products, and services that can solve current social problems and encourage local economic reactivation through new enterprises and job creation. Higher education has also played a vital role in these topics; nevertheless, many of the Mexico City population does not have access to suitable and affordable teaching-learning programs. Therefore, universities need to provide new programs that are available to society.

**Proposed solution:** A hybrid learning program is proposed, an alternative credential named Sensing, Smart and Sustainable ($S^3$) Enterprise Creation, earned in a bootcamp modality. This bootcamp is an intensive program (10 sessions, 40hrs.) that combines experienced instruction with a systematic methodology for creating new technology-based enterprises (startups and spin-offs), novel learning methods, use of current and emerging ICTs, and use of the modern and innovative infrastructure. The boot camp uses Blended-based Learning (BBL) and Learning by Doing (LBD) as the primary learning methods. It was created as part of a collaborative project between Tecnológico de Monterrey University and Mexico City's Government, seeking to promote technological and social entrepreneurship through new teaching-learning programs. Figure 5 illustrates the process carried out in this program.

***Methodology:*** The bootcamp was imparted to junior entrepreneurs from Mexico City through six involved technology-based projects: (1) Entrepreneurs in the area of collecting and recycling vegetable oil and the creation of biofuel; (2) Entrepreneurs in digital platforms for education; (3) Entrepreneurs in communication and streaming services; (4) Entrepreneurs in waste management and recycling; (5) Entrepreneurs in e-commerce promoting the exchange of goods and services, and (6) Entrepreneurs supporting the supply chain process to small producers in the agroindustry sector. This case study sought to demonstrate that the boot camp fostered vital competencies and the development of technology-based products/services. A mixed-method analysis was performed. A quantitative evaluation was carried out applying a post-survey of the students' perception of the soft competencies acquired during the boot camp and a qualitative evaluation of each project's improved value. Table 2 shows a summary of this case study.

Results & Discussion The obtained results show that participants could execute the activities that promote soft and hard competencies. Consequently, the participants defined the activities and strategies that would generate value for their startups. The following graphic presents the improved values for each participant project (See Figure 6). These results of the participant performance, delivered project, and applied surveys were validated. During the design of this teaching-learning program, the four core components

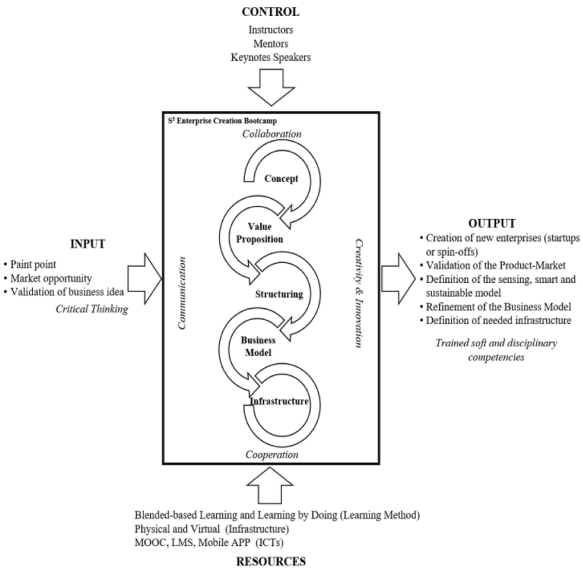


**Fig. 5.** The learning dynamic and components of the $S^3$ Enterprise Creation Bootcamp

**Table 2**
The $S^3$ Enterprise Creation Bootcamp summary table showing the core components of Education 4.0

**Alternative Credential:** $S^3$ Enterprise Creation Bootcamp
**Class Format:** Hybrid learning (Face-to-Face and Virtual Modality)
**Language:** Spanish
**Participant profile:** Junior Entrepreneurs and participants from startups and non-profit organizations
**Duration:** 10 sessions, 40 hours
**Experiment:** Mixed-method, quantitative approach using disciplinary and transversal rubrics

| | Core components of Education 4.0 | | | |
|---|---|---|---|---|
| **Modules** | **1. Competencies** | **2. Learning Methods** | **3. ICTs** | **4. Infrastructure** |
| **1. Concept**: Conceptualize a new business idea providing technology-based solutions aligned with the current priorities/problems of Mexico City. | *Soft*: Critical Thinking, Creativity, and Innovation. *Hard*: Promote the development of technology-based enterprises/spin-offs | Problem-based Learning | MOOC and Mobile APP | Designing rooms and a Gesell chamber |
| **2. Value Proposition**: Define and validate the value proposition of the product/service/ business provided by the conceptualized enterprise. | *Soft*: Collaboration and Cooperation. *Hard*: Use of Collaborative Virtual Platforms | Blended-based Learning and Learning by Doing | MOOC and Online resources | Designing rooms, Makerspaces, and the Decision-Making Laboratory |
| **3. Structuring**: State the structure of the defined enterprise considering purposes, functionalities, processes, and legal aspects. | *Soft*: Collaboration, Cooperation, and Communication. *Hard*: Virtual and Digital infrastructure | Active Learning and Hybrid Learning | MOOC, Web-conference systems, and Online resources | Virtual Classroom and Computational Labs |
| **4. Business Model**: Refine the business idea and build a robust business model. | *Soft*: Collaboration and Cooperation. *Hard*: Use of digital platforms | Challenge-based Learning and Blended Learning | MOOC, LMS, and Online resources | Virtual Classroom and LMS |
| **5. Infrastructure** Define the needed infrastructure or manufacturing system to be implemented. | *Soft*: Critical Thinking and Communication. *Hard*: Definition of Virtual and Digital infrastructure | Challenge-based learning | MOOC, LMS, Web-conference system, and Online resources | Virtual classroom and Decision-Making Laboratory |

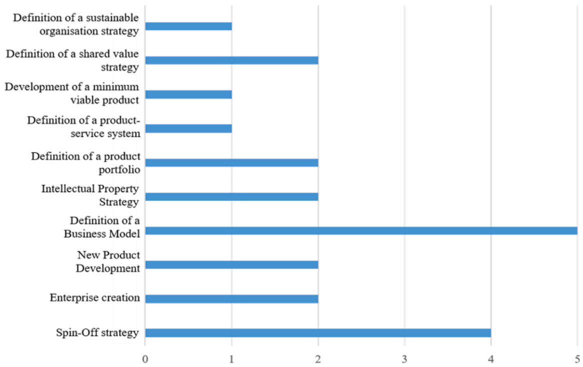


**Fig. 6.** Primary improved values for each of the six generated projects

of Education 4.0 were used as a reference to define the activities that aligned with the expected learning outcomes and achieved the training of critical competencies in the student technology entrepreneurs. These four components induced innovation by promoting new and emerging learning methods, technologies and facilities. Likewise, they improved the learning experience, obtaining highly relevant implementation results.

### *4.3. Case Study: Fostering multidisciplinary research in higher education through the Computing Intelligence, Mechatronics, and Biodesign Laboratory*

Research activity has played a crucial role in today's higher education institutions. These activities are desirable for generating knowledge and scientific products and developing transversal and disciplinary competencies. This case study presents the Computing Intelligence, Mechatronics and Biodesign Laboratory (CIMB). To achieve optimal training of students, educators must grant them the opportunity to test and adapt their acquired learning strategies. Including students in research that generates knowledge allows them to nurture their cognitive engagement through their achievements.

**Problem:** Traditionally, this laboratory conducted research projects with undergraduate engineering students in the last third of their degree, where they received a task to be completed. That strategy allowed the students to complete their graduation requirements while being challenged with a real-life problem to develop solution proposals. However, the learning and skills implementation were limited because the continuous student rotation limited progress, and the students were almost exclusively selected from engineering majors. These limitations affected the quality and products of the active research, the students' competencies, and their capability to test and improve their learning strategies.

**Proposed solution:** Two key elements that allowed maximizing the learning process and developing research products were identified. These elements were (i) student engagement and (ii) the age phase of inclusion. Through proper student engagement techniques, students involved in the projects could develop and test learning strategies that they might later integrate into academic courses. The inclusion phase allowed the students to develop long-term projects that motivated them to explore and implement additional technologies and collaboration strategies while widening their knowledge panorama. The long-term work allowed the students to develop additional materials, make connections, and provide evidence of their professional development or integration into the research field. The general structure for the implementation of this strategy can be observed in Figure 7. A summary of the implementation can be seen in Table 3, in which each of the modules mentioned in Figure 7 is further detailed.

**Methodology:** A strategy was placed to increase students' engagement and integrate alumni of previous semesters to improve research results and learning experiences. The implemented strategies included opening research routes having a social impact to obtain the social services center's approval. This allowed us to reach for students in the second third of the major. With the opening of additional research stays, this change allowed the students to receive academic credits while pursuing long-term research projects. The effect that these changes had on student recruitment through each academic period can be seen in Figure 8a.

In Figure 8b, the student population is divided into three groups for each academic period. The first division is students in the last third of the major. As shown in the figure, the number of students had a relatively stable growth, only diminishing in the periods with code ending "12," which refers to summer. (The periods ending in "11" refer to the period January-May, while "13" refers to August-November.) Even though the number of students in the second third of the major tended to increase, it diminished in the last third. This is a consequence of our laboratory connection mainly with the School of Engineering and Sciences; thus, we cannot offer topics to students in human sciences, arts, or business who could participate in the projects as a social services project. The second division refers to the students in the second third of the major. Most of these students were integrated through the social services focus. The project growth had to be limited because the laboratory workforce was overwhelmed by the considerable student interest. The last student group, just recently integrated into the projects, are in the first third of their major. These students participated initially as part of their grant service. The tasks they perform are related to introducing and understanding their major's core skills and competencies.

The lab's research focused mainly on the following categories: *(a) Advance Driving Monitoring for Assistance Systems (ADMAS),* involved in developing semi-autonomous vehicles; *(b) Emotional Domotics (Home Automation)*, involved in the development of home automation systems for the User Experience (UX) analysis and improvement, and *(c) Exoskeletons Design and User Experience (ExoDUX)*, research for the redesign and analysis of exoskeletons based on UX.

**Results and Discussion:** Some of the results of the students' integrations are collected in Figure 8b and compared with the production before the strategy implementation. In the table, the first total row (Total 2010-2014) refers to the production throughout

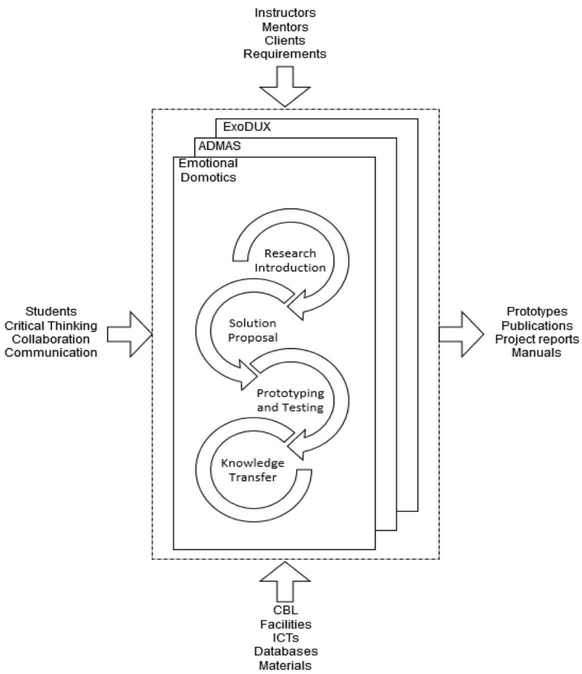


**Fig. 7.** Learning and development methods for CIMB research projects

**Table 3**
The CIMB Laboratory case-study-summary table, showing the core components of Education 4.0

**Research Program:** CIMB multidisciplinary research projects development
**University:** Tecnológico de Monterrey, Mexico
**Class Format:** Hybrid, Face-to-Face, and virtual
**Language:** English and Spanish
**Participants:** 50-60 undergraduate students
**Duration:** 16 weeks 48 hours
**Implementation:** Research and innovation development assessed with rubrics based on objectives and products

| | **Core components of Education 4.0** | | | |
|---|---|---|---|---|
| **Modules** | **1. Competencies** | **2. Learning Methods** | **3. ICTs** | **4. Infrastructure** |
| **1. Research Introduction**: Students receive a general background and tools. They are tasked with finding and identifying state-of-art based on their specialties. | *Soft:* Critical thinking. *Hard:* Use of design engineering platforms and Data Bases | CBL and Active Learning (AL) | Research databases, MOOCs, E-Learning tools. | Collaborative rooms, virtual and physical libraries |
| **2. Solution proposal:** Identify limitations and areas of opportunity of the topic. Define and generate tasks and coordination plan. | *Soft:* Creativity and Innovation. *Hard:* Design and development of technology-based products | CBL, AL, Mentoring, and Inspiring Educators | LMS, virtual collaboration platforms | Virtual and digital schools and innovation spaces |
| **3. Prototyping and testing:** Develop the systems or tools prototypes that allow the implementation of the proposed solutions | *Soft:* Collaboration and Cooperation. *Hard:* Rapid prototype techniques and tools | Learning by Doing | IoT, robotics, simulators, and AI tools | Makerspaces, virtual and physical labs, movement capture rooms |
| **4. Knowledge transfer:** The students must present their results at the end of the project to a committee of evaluators. They must also generate a manual, project report, publication, or prototype to be transferred. | *Soft:* Communication. *Hard:* Technical documentation and creation of scientific products | Lifelong Learning | MOOC, LMS, and Online resources | Connected classrooms |

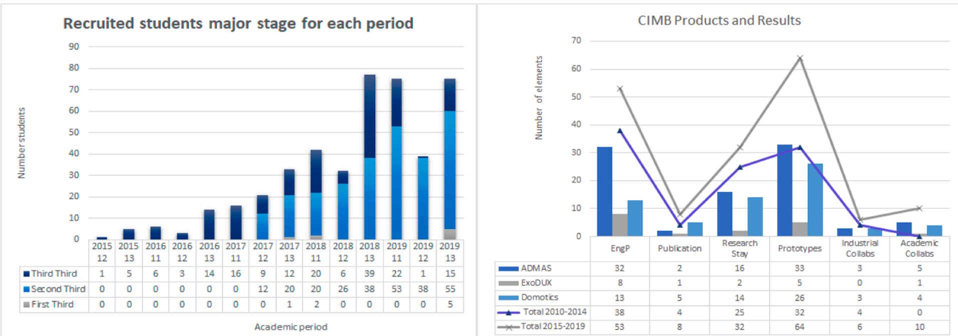


**Fig. 8a.** (left) Student population per academic period Fig. 8b. (right) Condensed CIMB products-and-results graphic with a comparison between periods 2010-2014 and 2015-2019.

the years before the implementation, while the last row (Total 2015-2019) refers to the production in the period corresponding to the strategy. In the table, the "EngP" column refers to engineering projects being completed (report or thesis). The "publications" are works of students that resulted in a publication in a conference or journal. "Research Stay" indicates topics where the students focus on developing or implementing research protocols and analyses. The "Prototypes" can be either physical elements or algorithms that allow the treatment, processing, or display of data. These prototypes allow the projects to continue through various phases, thus facilitating fast preparation of new elements and rapid development of new challenges. The consequences of this progress and the students' engagement included attracting collaborators, which in this table are divided into "Industrial" and "Academic." A collaborator aids the research by providing financial, technological, material or educational assistance, or even human resources. In this figure, the rows corresponding to "ADMAS," "ExoDUX," and "Domotics" are the projects developed during the strategy implementation and summed in the "Total 2015-2019."

Implementing the Education 4.0 concept in designing these strategies helped determine the specific activities to be performed and the infrastructure to be used in the different categories of the presented projects. Therefore, the critical competencies developed in the research and the activities carried out by the students were aligned to foster collaboration between the students and researchers. This allowed the generation of strong ties between students and researchers, created inspiring figures and facilitated challenging scenarios where the students collaborated on multidisciplinary teams to face current challenges. Because of this strategy, multiple students developed self-study and lifelong learning strategies that they will appreciate when they integrate into professional life. Other students develop such affinity to research that they end up researching in graduate school.

## 5. Conclusions

Current challenges in higher education are not just limited to educational and social issues. They are also problems brought by rapid technological advancement and the need to develop essential competencies in today's students, encouraging them to grow technically, technologically, analytically, and with the ability to think critically. Achieving this requires new programs, products, and services that consider the necessary components in current education.

In this work, we propose four core components that shape the concept and vision of Education 4.0. Educational innovators can design new educational models, teaching tools, learning methodologies, and infrastructures by considering these proposed core components. We also present three case studies to illustrate how programs adopted the concept and vision of Education 4.0. Each case study showed positive effects, such as generating new knowledge, transferring information among peers, creating innovative solutions, and using technological resources available during implementations. The proposed four core components of Education 4.0 as a reference framework for design processes can be useful for enablers and initiatives that can align with the vision and concept of Education 4.0 and propose solutions that face current challenges in this sector.

Among the study's limitations is that it was based on case studies, opening a window to expand the results through experimental studies. Although this article was defined in higher education and in instances of "formal education," the components of Education 4.0 can be applicable to different educational levels and be extended to non-formal and informal educational environments.

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**Julieta Noguez.** Writing – Review and Editing
**José-Martin Molina-Espinosa**. Writing – Review and Editing
**María-Soledad Ramírez-Montoya.** Writing, validation and investigation
**Sergio A. Navarro-Tuch,** Writing – Review and Editing
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## Declaration of Competing Interest

All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

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