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Scaling Complex Thinking for Everyone: A Conceptual and Methodological Framework

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Nowadays, complex thinking remains a critical topic for researchers and academicians in higher education. It is considered a core competency for designing and developing solutions proposals for current societal problems. However, there is still a need to create and implement innovative teaching-learning systems and initiatives that support training and development of desirable transversal and disciplinary competencies that promote complex thinking in students. In this context, Open Science has become a fundamental resource to accelerate research processes, enrich education, build new ways to analyze complex social realities, and provide affordable infrastructures with massive impact to close inequitable gaps in different regions. This paper introduces the “Reasoning for Complexity” Interdisciplinary Research Group (R4C-IRG) that connects and develops these themes, providing a conceptual and methodological framework with three fundamental approaches (i) Open Science, (ii) Open Innovation, and (iii) the Education 4.0 framework. It allows us to propose an Open Collaborative Network Model for knowledge generation and transfer initiatives, the development of collaborative and entrepreneurial projects, and technology transfer to scale levels of complex thinking for higher education students.

CCS CONCEPTS

• Social and professional topics • Professional topics • Computing education • Computing education programs • Information systems educationn

Additional Keywords and Phrases:

Complex thinking, Open Science, Open Innovation, Education 4.0, Educational Innovation, Higher Education.

1 Introduction

The future educational horizon includes complex thinking as a development challenge for a society seeking new solutions to critical problems confronting higher education and lifelong learning. Access to data and knowledge through open, collaborative approaches such as Open Science and Open Innovation are essential resources to accelerate teaching-learning processes in the Education 4.0 framework. They facilitate new ways to analyze complex social realities and provide affordable infrastructure for massive impact in closing inequitable gaps in different regions. Today more than ever, it is essential to enhance research processes and promote innovation and educational strategies to develop entrepreneurial skills based on critical, scientific, and systemic thinking.

In 2015, a historic moment occurred, as 193 countries joined and signed an ambitious Sustainable Development Goals (SDGs) agenda. Among the 17 SDGs, SDG 4 focused on guaranteeing inclusive and quality education for all and promoting lifelong learning. This unquestionably necessary objective to improve the well-being of present and future generations suggests that SDG 4 is essential to achieve all the other SDGs.

Under this scenario, the “Reasoning for Complexity” Interdisciplinary Research Group (R4C-IRG) was formed to scale complex thinking for everyone through Open Science. It aims to characterize both the concentration and the fragmentation of the reasoning for complexity of various disciplines through Open Science. Ultimately, the R4C-IRG aims to contribute to the SDGs while promoting responsible citizenry by generating and transferring open knowledge, developing open, collaborative projects, and promoting entrepreneurship through open technology transfer processes. The starting point addresses SDG 4 by answering the research question: How can complex reasoning be characterized and scaled through Open Science to support inclusive, equitable, quality, world-class education that provides lifelong learning opportunities for all?

This document outlines the R4C-IRG working method through the conceptual delimitation and integration of the critical components: the 2030 agenda for the Sustainable Development Goals, Open Science, and competencies for complex thinking. It introduces the conceptual and methodological perspectives of the Open Collaborative Network Model, followed by expected outcomes and conclusions of the interdisciplinary initiative.

1.1. Equal Access to Science, Technology and Innovation

Multi-stakeholder collaboration in science, technology and innovation is crucial to achieving the objectives of Sustainable Development in the UN’s 2030 Agenda. International efforts have empowered vulnerable communities to access science, technology, engineering and mathematics education, and training and research activities. They have raised public awareness and inclusion in decision-making processes to overcome legal, economic, and socio-cultural barriers, thus, encouraging the development of the knowledge society, reducing the learning gap, and creating sensible educational policies [1]. However, despite the growth of initiatives to foster greater citizen participation in science, the World Economic Forum (WEF) estimates that in 2020, 3.7 billion people without internet connectivity fell behind due to the pandemic. The challenge now is urgently to determine the most promising innovations to bridge the present digital divide [2,3], which is linked to inequalities in the living conditions of the population [4,5]. Indeed, the 21st-century gap is not limited to digital literacy. Needs include contributions to personalized learning, sustainable development, studies for equal access, training for employability skills, and inclusion of gender and vulnerable groups, all required to achieve SDG 4.

Indeed, SDG 4 focuses on including all groups lacking access to education. It looks to technology to improve livelihoods effectively, a goal attended from many perspectives, such as the “social justice-oriented interaction design”

[6, 7] that seeks to avoid unfairness and inadequacy in design approaches by considering recognition, understanding, and accountability. The discussion is about the opportunity for designers and technology developers to assure equal and inclusive forms of innovation. Nevertheless, even without internet access, the latent need of marginalized local communities to solve problems has led to the emergence of community empowerment movements focused on co-creating technology-driven solutions [8]. For instance, citizen participation in science has been reborn through the Maker Movement that emerged at the beginning of the millennium. This phenomenon has seen the rise of amateur scientists who informally learn how to solve particular problems using electronic devices and reused materials. Known as Citizen Science, it relies on the open generation of consumer technology and awareness of tools for experimenting under the scientific method. It has been changing people's perception of what science is all about, expanding the scope for the general public with concepts such as "slow science," which include single-subject quantification methods [9]. Indeed, when struggling marginalized communities are provided with Internet access, the scope of their initiatives multiplies, allowing them to share their discoveries through open digital platforms and get feedback from other citizens.

Furthermore, their local problem-solving projects might get replicated and improved in other localities, thus achieving the openness of science (Open Science). The processes, data, and findings become accessible worldwide in formal, non-formal, or informal educational settings. However, generating and making information available is just one side of a successful approach to achieving Open Science. The real challenge is to manage the flow of complex information in a manner that helps future citizen scientists to reason about the meaning and application of available knowledge that has been produced somewhere else.

1.2. Complex Thinking Meta-competency

The horizon of quality education inspires us to develop the necessary training for reasoning for complexity as a societal priority in searching for new solutions. The challenge will be to form citizens with critical, scientific, systemic, and entrepreneurial thinking committed to sustainable development and emotionally intelligent, empathetic and cooperative [10]. Complex thinking is a meta-competency with a high potential to contribute to future education where students use critical, creative processes or divergent reasoning [11]. Complex thinking arises from the fusion of critical and creative thinking and is based on rationality and creativity. It promotes the search for solutions, requires tolerance to uncertainty and self-criticism, and coordinates problem-solving with self-regulation of the thinking process (metacognition) [12, 13].

Some key strategies for achieving complex reasoning competencies include challenge-based learning, problem-based learning, case-based learning, and project-based learning. Schott [14] states that complexity in and deviations from the formally defined processes occur and function with complex reasoning. It is shaped by the interrelation and complementarity among critical thinking, creative thinking, and metacognition [15]. Complex thinking assumes heterogeneity, interaction, and chance. These elements, considered as a systemic totality, are based on three principles: a) dialogic principle (it does not assume the overcoming of opposites but establishes that the antagonistic terms coexist); b) principle of recursivity (the effect becomes a cause and the cause becomes an effect), and c) hologrammatic principle (it sees the parts in the whole and the whole in the parts) [16].

1.3. Open Science, Open Innovation and Education 4.0

To promote initiatives that scale complex thinking for everyone, one must identify strategies to construct desirable environments and tools for training and developing core competencies that promote complex thinking in individuals. In this sense, it has been found that the participation of individuals in real scenarios and their interactions with social problems and challenges and their participation in the encouragement of solutions that help achieve SDGs are desirable environments to train these competencies. Therefore, this research group chose Open Science to use and develop open resources to accelerate and shorten development processes and apply open innovation strategies through multidisciplinary networks, mainly implementing the quadruple helix model. In addition, higher education institutions are considered pivotal channels for these cooperative and collaborative strategies. They foster two main activities. (i) Design particular teaching-learning systems that promote complex thinking, including didactic products-services, teaching-learning processes, and desirable environments and facilities; (ii) Link collaborative projects with key actors such as citizens/society, companies, higher education institutions, and government. Consequently, mobilizing open knowledge requires a strategic vision that considers the influence of the innovative ecosystem and the alliance of economic systems. Furthermore, it is essential to ground the flow of information in established frameworks and models that make it possible to demonstrate the impact of the projects under observation. Therefore, three key constructs have been considered for studying the process of knowledge generation linked to complex thinking: Open Science, Open Innovation, and Education 4.0. Figure 1 shows the three proposed key constructs for scaling complex thinking for everyone.

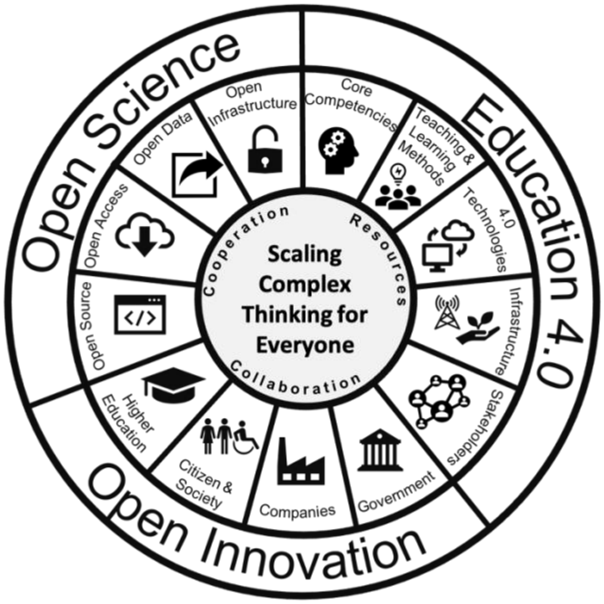

Figure 1: The three proposed key constructs for scaling complex thinking for everyone: Open Science, Open Innovation, and 4.0 Education.

Open Science. Now frequently used by academia, scientific communities, and the wider public, it promotes cooperation and collaboration to accelerate research processes, enrich education, and stimulate innovation and technology transfer through open sharing of data, information, and knowledge. Open Science links research with open knowledge generated by the academic community and various sectors that work collaboratively. Among its premises is the support of scientific research and data dissemination accessible at all levels, including practices in which different people participate and contribute, share research data, laboratory notes and other research processes freely and openly [17]. Open Science brings the opportunity for co-creation and open innovation.

Open Innovation. Generally known as a model, it defines the networked nature of innovative processes through collaborative strategies that combine internal and external ideas, resources and technologies. It creates synergies among various multidisciplinary actors from different organizations [18]. In practice, it serves as a framework to shape collaboration among key actors. Advances in this area are still emerging. The open science, knowledge co-creation, and open innovation triangle presents an opportunity to contribute research to open educational theory and practices [19]. As a thematic issue linked to sustainable development, open innovation contemplates the generation of knowledge, creation of new products and services, transfers, multidisciplinarity and collaboration, and an opportunity to expand its incidence in the educational field [20].

Education 4.0. This construct emerges from the relationship between the particular technologies of the fourth industrial revolution (Industry 4.0) and the education sector, taking advantage of the attributes of current and emerging technologies (connectivity, virtualization, digitalization, datafication, and "smartification"), known as 4.0 technologies. In the educational context, these technologies are combined with active learning methods, innovative didactic and management tools, and smart and sustainable infrastructures to improve pedagogical processes [21]. In higher education, Education 4.0 fosters the vision to graduate a new generation of highly competitive professionals capable of applying the proper physical and digital resources for innovative solutions to current and future societal challenges. Within the framework of Education 4.0, five key enablers achieve this vision: (i) training crucial transversal and disciplinary competencies, (ii) applying new active learning methods and learning modalities, (iii) implementing current and emerging 4.0 technologies, (iv) employing innovative infrastructure including facilities, architecture, services, and platforms, and (v) inducing active participation and collaboration among key stakeholders.

2 Method: Open Collaborative Network Model

The R4C-IRG contributes to the future of education with high potential models to explore the horizons of Education 4.0. The latter prepares and trains a new generation of highly competitive professionals capable of applying the correct physical and digital resources for innovative solutions to current and future societal challenges [22]. Therefore, by developing new teaching and learning systems based on complex thinking strategies for personalized learning, this research group aims to achieve the 2030 Agenda for the SDGs. The objective of the R4C-IRG is to scale mastery of complex reasoning competencies in higher education students through relevant teaching-learning systems supported by Open Science strategies and 4.0 Technologies. These are linked to quadruple-helix projects (university-industry-government-civil sector). In addition, mixed-methods measurements will be made with pre-test and post-test instruments (quantitative), and the relationships with the cases assessed through interviews and rubrics (qualitative) [23]. Then, students will develop their complex reasoning competency to respond to critical issues of their environment, supporting the SDGs.

2.1 Conceptual and methodological framework

The outlined conceptual and methodological framework is based on Open Science, Open Innovation, and the Education 4.0 framework. It contemplates designing, developing, and implementing new, personalized learning pathways, innovative didactic and management tools, and smart and sustainable infrastructures complemented with emerging open ICTs and 4.0 Technologies. Therefore, the R4C-IRG's Open Collaborative Network Model focuses on a series of activities that links research and practice with an Open Science and Open Innovation perspective: (a) envisioning new solutions for the future of education with interdisciplinary networks; (b) developing problem-solving strategies through experimentation and learning laboratories for social innovation; (c) designing national and international ventures; (d) experimenting in world-class classrooms with diverse and inclusive environments; (e) prototyping educational environments for lifelong learning; (f) demonstrating results with applied research; (g) expanding applications in different universities; and (h) transferring solutions to society to support the social appropriation of knowledge and sustainable development [24, 25, 26, 27].

2.2 Open Collaborative Network Model components

Figure 2 presents the proposed conceptual and methodological Open Collaborative Network Model. The network contemplates 5 main blocks: a processing block for Open Science and Open Innovation as the axis of the general proposal, the inputs that feed the process, the control methods used during the development, the resources that make up the tools necessary for the operation, and the outputs that are the contributions and findings of the process.

As inputs, the entries are the primary established challenges facing this proposal, some of the requirements to be considered, and the main problems to be addressed. The challenges include sustainability, with social issues and the exhortations to be considered.

The control block includes these characteristic challenges analyzed and assessed by tools (e.g., monitoring Open Science general level of achievement per the nine Technology Readiness Levels [TRL]). Different research methods applicable to each challenge and their characteristic environments will be considered in due course. In addition, the main facilitators of the aspects and knowledge on which our work scheme is based are highlighted. For example, mixed-methods measurements will be made with pre-test and post-test instruments (quantitative) and the relationship with the cases through interviews and rubrics (qualitative).

The resources block includes the most relevant emerging enablers of Education 4.0, such as technologies, teaching and University staff, competencies developed in learners, necessary infrastructures, and emerging teaching methods.

The conceptual processing block integrates Open Science and Open Innovation for entrepreneurship through the generation, collection, and application of knowledge. Its Education 4.0 methodological framework links design, development, and implementation of personalized learning methods with quadruple-helix projects. Collaboration of these entities throughout the implementation will be necessary to consolidate the competency development of complex thinking, with models that lead students to respond to critical issues of their environment to achieve sustainable development.

The results are shown as Outputs, which gradually and significantly yield long-term knowledge, complex thinking, and student assertiveness. Three major categories are considered: Knowledge transfer (e.g., Open Science and Open Innovation platforms), Collaborative projects (e.g., an extended collaborative network for product/service development), and Entrepreneurship dissemination (e.g., technology transfer and intellectual property management).

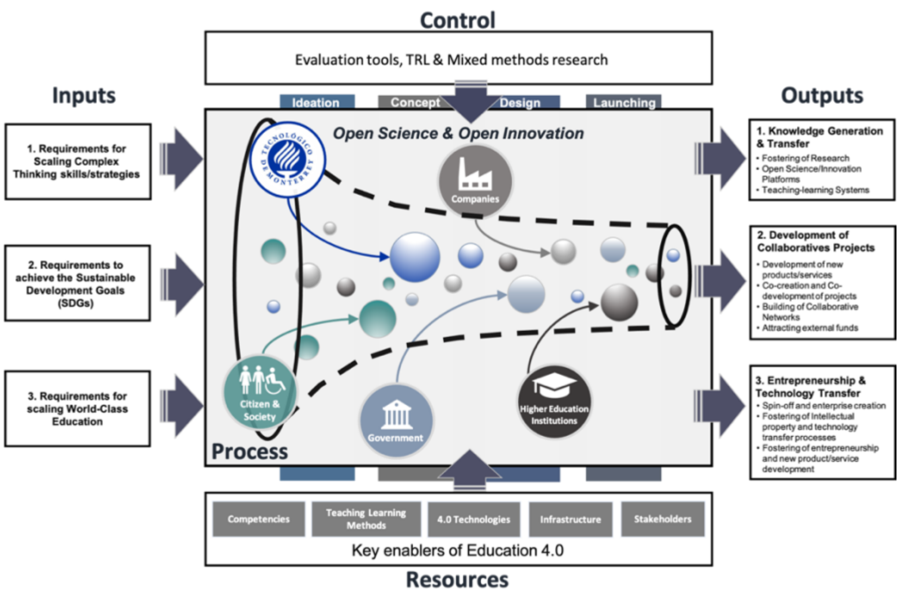

Figure 2. R4C-IRG's Open Collaborative Network Model

3 Analysis and Expected outcomes

The main results of R4C-IRG will provide solutions enabling the scaling of world-class education through innovative and value processes focused on solving complex problems. The processes will be assessed with qualitative indicators (social appropriation, solutions, qualification) and quantitative tools and methods (entrepreneurship, technology-based models, interdisciplinary projects of intersectoral articulation). In the next three years, this research group will contribute to the future of education through initiatives classified into three main groups (i) Knowledge Generation and Information Transfer, (ii) Development of Collaborative Projects, and (iii) Entrepreneurship and Technology Transfer. To achieve this, the R4C-IRG will reference a management model based on innovation processes and the development of innovative talent. Therefore, the proposed activities will be controlled and follow a structured approach for decision-making and the correct use of resources [28].

Consequently, this interdisciplinary research group will pursue outcomes, products, services, programs, and platforms that foster interdisciplinary and multi-sectoral collaboration. Under the Education 4.0 framework, an international network will prototype a world-class open classroom (Open Learning scenarios for competencies development) while promoting active learning and technology transfer (entrepreneurship) among different universities and organizations. A core value of the R4C-IRG is the promotion of reasoning competencies and skills in High-Ed students and lifelong learning environments to keep up with complexity, entrepreneurship, and transformational leadership to face emerging challenges.

4 CONCLUSIONS

Quality education must be addressed worldwide to secure even and equitable global development in the years to come. To conceive mechanisms that attain Sustainable Development Goals (or at least move forward in that direction), it is critical that researchers from every discipline collectively embrace imagining the future of education. Increasing the clusters of methodologies that enable open, inclusive, accessible, innovative and disruptive learning approaches elevates the possibilities for citizens to achieve the well-being contemplated by the SDGs. Moreover, every discipline and educational institution should share knowledge and findings through collaborative actions to make a global impact.

The R4C-IRG, through the proposed Open Collaborative Network Model, seeks to channel global knowledge through the procurement of open access to Science, Technology and Innovation per the UN 2030 Agenda, addressing the global learning gap through new models and digital learning environments. Mainly, the process aims to characterize and develop complex thinking in higher education students within the framework of Education 4.0, scaling this competency with a world-class vision.

We have articulated an educational research initiative to apply open knowledge within a methodological framework based on Open Science and Open Innovation, which will involve participatory design processes. However, the scope of the Open Collaborative Network Model's application is still to be decided since the particular interests of the potential national and international partners will be added to the initiatives arising from these collaborations. In addition, the context of stakeholders from region to region becomes so varied that validation of the model may involve generating local or continental versions to ensure the desired impact.

Some of the expected outcomes of the R4C-IRG in the short term include developing an Open Science model to scale complex thinking, including diagnosis, future scenarios generation, proof-of-concept, validation of the model, and design of the transference process.

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