European Digital Transformation Needs Indicators of Informatics Competence

By Andrew McGettrick, *University of Strathclyde,* Michael E. Caspersen, Aarhus *Aarhus University,* Judith Gal-Ezer, *Open University* and Enrico Nardelli, *University of Rome Tor Vergara*

In today's world it is crucial that individuals, regardless of their position or daily activities, be digitally skilled. Digital skills sit at the application level, where people must be able to operate, through technological devices and systems, with applications. This happens in a variety of sectors: It could be argued that in today's world, digital applications are utilized in some capacity across all areas of services, production, and communication.

However, it is important to remember that all these artifacts are driven by the scientific discipline of informatics.[1] That is why concepts like data, algorithms, computing machines, programming, communication, and coordination must be part of the standard school education, much like those of force, energy, cell, organism and molecule. The practical side, that is, the equivalent of the laboratory for traditional sciences, must also be part of this education. Moreover, digital technology is affecting human society, and it is therefore necessary that all students are aware of the implications that technology, developed on the basis of Informatics principles, can have on human beings and their relationships.

Many educational systems around the world are aware of the importance of including informatics as part of the general education for all [10, p.87]. However, in the European Union (EU), the important policy issue of how to monitor the progress of the various national educational systems toward the goal of preparing citizens to thrive in a digital society has been focusing mainly on digital skills for almost 20 years, forgetting the need of educating students about informatics as a science. In a previous publication [2] there was a discussion on informatics as a science (presenting the Informatics Reference Framework). In this article, we discuss the relationship between digital skills and the science of Informatics, presenting the evidence that the current approach followed in the EU for measuring progress in the digital transformation of society is not fit for the purpose and there is instead the need to develop a way of measuring scientific competence in informatics.

The difference between digital competencies and the basics of the scientific discipline is shown in Figure 1, which was inspired by a similar drawing by Simon Peyton-Jones [18]. What is needed to operate above the sea level is the set of digital skills, but what is required to be able to move fluently and smoothly below the sea level is the knowledge of the scientific discipline of informatics. This distinction is too often not clear either to the everyday citizen or to policymakers.

A similar picture can be drawn for other sciences, e.g. physics, shown in Figure 2. Its fundamental concepts underlie a vast array of possible applications involving physical properties of matter in many fields and in everyday life. All citizens during their compulsory school-years receive a basic scientific education, so as to be able to understand a world full of industrial machines. Then, in the final years of school, those wanting to follow a technical specialization with a view of entering the workforce soon, will choose an elective path leading to this goal, while those wanting to deepen their understanding of the scientific or design aspects will continue to the university. In both cases they will be able to start from an acceptable level. All the others will remain with a scientific knowledge adequate for an industrial society. In any case, it will be generally clear to every educated citizen that, for example, the knowledge of the principle of energy conservation and the role of dissipative processes concerns the level "below the sea," while the operational skills involving physical properties such as how to measure temperature and insulate bodies regard the level "above the sea." Nobody, generally speaking, will get mixed up. Therefore, nobody will mistake a person skilled in measuring temperature for a physicist expert of the scientific principles of heat transmission.

On both levels, well-educated teachers are the cornerstone needed for the introduction of each of the levels into the school system.

INFORMATICS AS A LANGUAGE

In 1967, Danish Turing Laureate Peter Naur wrote about the importance of including informatics in general education [16, 17]:

"To conceive the proper place of informatics in the curriculum, it is natural to compare with subjects of similar character. One will then realise that languages and math-

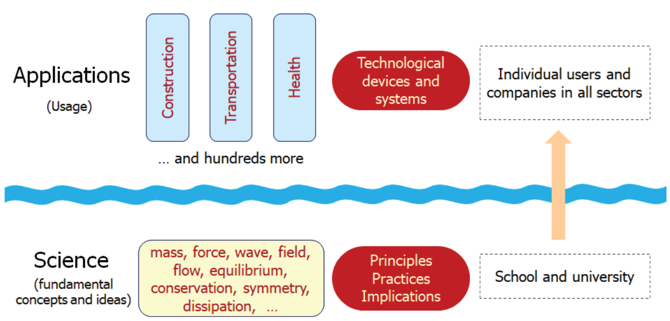

Figure 1: Application and Science levels for Informatics.

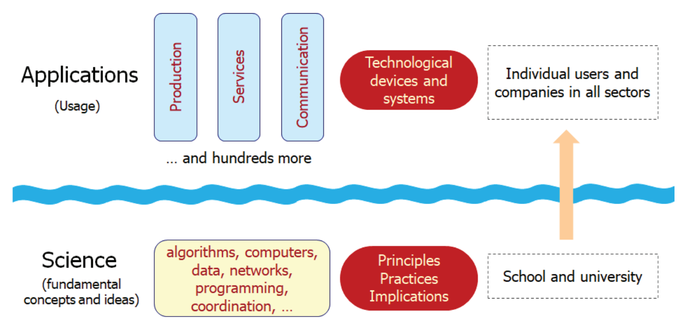

Figure 2: Application and Science levels for Physics.

[1] In Europe, the terms "Informatics" is used to denote the discipline that in other countries is called "Computing" or "Computer Science." In the Informatics Reference Framework for School [2], we have synthetically described it as "...the science of automated processing of representations, covering the foundations of computational structures, processes, artefacts and systems, as well as their software designs, their applications, and their impact on society."

ematics are the closest analogies. Common for the three is also their character as tools for many other subjects … Once informatics has become well established in general education, the mystery surrounding computers in many people's perceptions will vanish. This must be regarded as perhaps the most important reason for promoting the understanding of informatics. This is a necessary condition for humankind's supremacy over computers and for ensuring that their use do not become a matter for a small group of experts, but become a usual democratic matter, and thus through the democratic system will lie where it should, with all of us."

Naur's plea to properly include informatics in general education with a standing similar to languages and mathematics and his arguments for the plea are no less relevant today, more than half a century after their articulation.

George Forsythe, a former ACM president and one of the founding fathers of computer science education in US academia, in 1968 wrote [12]:

"The most valuable acquisitions in a scientific or technical education are the general-purpose mental tools which remain serviceable for a lifetime. I rate natural language and mathematics as the most important of these tools, and computer science as a third."

In school, informatics will—among many other things—offer the possibility of describing and simulating phenomena whose mathematical modeling is too advanced for the level of development of students. For example, when discussing ecological principles in natural sciences, one typical case study is the predator-prey relation. Its understanding through simulations done via a programmatic modeling of how both prey and predators increase or decrease is much more accessible than a description through differential equations.

This approach, useful for schools, carries over into the actual work of many sciences.

In the report Science 2020 [7], scientists from all over the world and various disciplines came to the conclusion that: *"Indeed we believe computer science is poised to become as fundamental to biology as mathematics has become to physics … what this report uncovers, for the first time, is a fundamentally important shift from computers supporting scientists to "do" traditional science to computer science becoming embedded into the very fabric of science and how science is done, creating what we are prepared to go so far as to call "new kinds" of science."*

In 2006, Bernard Chazelle [3] wrote that informatics will have the same role in the 21st century as mathematics has had in the 20th century, as a language to describe (artificial and natural) phenomena, much as Galileo meant when he wrote *"the book of nature is written in the language of mathematics"* [14].

Additionally, Bruno Frey made a similar remark focusing on those disciplines which he calls "reactive" [13]. These are the ones whose objects of study are not passive elements, which cannot react and change their behavior as the result of their modeling (as happens with weather forecasts), but reactive monads, which are able to either sense the environment or understand constraints placed on their behavior (or both) like biological and social entities.

A complementary description in this direction is the one provided by Brian W. Arthur [1], who discusses those sciences which use verbs to describe their objects of study instead of names. It is not easy for mathematics to describe in a natural way the reactive interplay between those objects and environments they are immersed in, while informatics excels at it. One example of the fundamental conditional construct applied to events might be "if this event happens then generate a new entity else combine these two existing entities:" it expresses both the reaction to something happening in the environment and acting onto it. This is the motivation informatics is nowadays the preferred language used to model scenarios in social and life sciences.

MEASURING INFORMATICS COMPETENCE

In the light of this discussion, if one wants to measure the progress a society is really making toward the goal of preparing citizens with a scientific competence adequate to do well in an increasing digital world, the level of diffusion of basic principles and concepts of informatics should be gauged rather than simply detecting the amount of use of digital tools.

In the remainder of the article, we first make a comparison between three different frameworks to measure digital competences, two national ones (UK and Italy) and one used by the EU. Then we analyze in detail the approach used in the EU to measure the progress toward a digital society and argue in detail that it is not the right measurement tool. Finally, we propose the introduction of a framework that can allow a more precise measure of the general level of scientific competence in Informatics used by citizens. This would allow to prepare a uniform test for measuring Informatics competence, as the Program for International Student Assessment (PISA), administered by the Organization for Economic and Co-operation and Development (OECD) [19], is currently doing with their tests for mathematical and linguistic competence.

We think that reflecting on frameworks for measuring education is an issue of interest for educators, who cannot simply teach without worrying also about how bureaucrats measure the results of their educational efforts.

COMPETENCE FRAMEWORKS FOR DIGITAL SKILLS

UK. A first reference document is the Essential Digital Skills Framework defined by the UK Department of Education, in cooperation with various international organizations [8]. It has a highly pragmatic structure focusing on pure skills, hence it is probably more easily usable for a mass education activity and the evaluation of its outcomes. It is organized as six areas, all but the first partitioned in life skills and work skills and all providing examples.

1. Digital foundation skills (underpinning all the remaining ones)
2. Communicating (what is needed to communicate, collaborate, and share information)
3. Handling information and content (the skills required to find, manage and store digital information and content securely)
4. Transacting (what is needed to register and apply for services, buy and sell goods and services, and administer and manage transactions online)
5. Problem solving (the skills required to find solutions to problems using digital tools and online services)
6. Being safe and legal online (what is required to stay safe, legal and confident online).

ITALY. A second reference document is represented by the "Syllabus of digital skills for the Public Administration," defined by the Italian Department of Public Administration to describe the set of minimum skills required of each public employee who is not an IT specialist. The document, developed in 2018, was released after a public consultation in 2019 and updated in 2020; see [4].

Its high-level organization is similar to the EU's Digital Competence (DigComp) Framework (see section 2.3), but it has a simpler structure. In particular, while it features five competence areas, like DigComp, it only has three proficiency levels (Basic, Intermediate, Advanced).

Unlike the UK Framework, the Italian Syllabus covers both knowledge and skills. The rationale for its simplicity is in the "awareness that the more complex dimensions of competence, regarding capacity, autonomy, and responsibility, are not only more difficult to develop but also require a complex set of tools for their measurement. Conversely, knowledge and skills can be more easily developed through traditional educational means and can more easily verifiable." Indeed, the issue of how to measure what people have actually learned is a highly critical issue, considering that, for Italy alone, this involves 37 million citizens aged between 18 and 65 years.

The Syllabus is organized into five areas of competence, for which it identifies a total of 13 specific competences, as described in Table 1.

Its structure is also coherent with what is required by the Law n.92 of 2019 to Italian schools concerning digital citizenship education [15].

Both the UK and the Italian documents provide a characterization of digital competences focusing on the needs of citizens in a digital society: be informed, interact, communicate, protect personal data, solve problems using digital platforms and services.

EU. A third reference document is the Digital Competence (DigComp) Framework, created by the Joint Research Centre of the European Union, first released in 2013 and subsequently updated until the current version 2.2, recently published [6].

This document is organized with five areas of competence, for which it identifies a total of 21 specific competences and eight proficiency levels, which for each competence describe the different degrees of operational capability that can be reached, as described in Table 2.

Table 1: The Italian Digital Competence Framework.

Area	Competence
1. Data, information and digital documents	1.1 Manage data, information and digital content 1.2 Produce, evaluate and manage digital documents 1.3 Know Open Data
2. Communication and sharing	2.1 Communicate and share within the administration 2.2 Communicate and share with citizens, companies and other public administrations
3. Safety	3.1 Protect devices 3.2 Protect personal data and privacy
4. Online services	4.1 Know about digital identity 4.2 Online service provision
5. Digital transformation	5.1 Know about goals of digital transformation 5.2 Know emerging technologies for digital transformation

Table 2: The EU Digital Competence Framework.

Area	Competence
1. Information and data literacy	1.1 Browsing, searching and filtering data, information and digital content 1.2 Evaluating data, information and digital content 1.3 Managing data, information and digital content
2. Communication and collaboration	2.1 Interacting through digital technologies 2.2 Sharing through digital technologies 2.3 Engaging in citizenship through digital technologies 2.4 Collaborating through digital technologies 2.5 Netiquette 2.6 Managing digital identity
3. Digital content creation	3.1 Developing digital content 3.2 Integrating and re-elaborating digital content 3.3 Copyright and licences 3.4 Programming
4. Safety	4.1 Protecting devices 4.2 Protecting personal data and privacy 4.3 Protecting health and well-being 4.4 Protecting the environment
5. Problem solving	5.1 Solving technical problems 5.2 Identifying needs and technological responses 5.3 Creatively using digital technologies 5.4 Identifying digital competence gaps

The DigComp framework appears to have an excess of articulation in the description of the various competence areas, with the inclusion of skills (e.g., programming) that go beyond the scope of operational digital skills but instead specifically belong to Informatics. A framework for measuring operational competences should focus on this level ("above the sea," in Figures 1 and 2) without extending to scientific principles ("below the sea"). Just as one does not have to understand the gravity force to be able to use a scale and weigh a kilogram of something, knowing how to program is not needed to be able to use digital devices.

Moreover, the eight levels of proficiency described in the DigComp framework makes reference to a scale that reaches a degree of competence typical of the top layers of university education or ICT professions. To illustrate this point, we report here the description of the upper two levels of proficiency (in the "highly specialized" stage) for the "programming" competence: (level 7): "I can create solutions to complex problems with limited definition that are related to planning and developing instructions for a computing system and performing a task using a computing system, and integrate my knowledge to contribute to professional practice and knowledge and guide others in programming;" and (level 8), "I can create solutions to solve complex problems with many interacting factors that are related to planning and developing instructions for a computing system and performing a task using a computing system, and propose new ideas and processes to the field." It seems really difficult to maintain that these levels of proficiency might be required for an average citizen. Indeed, a digital competence framework should support measuring the skills of large and varied segments of the population, which is difficult to do if topics are not simple operational ones. Finally, version 2.2 of DigComp explicitly refers to hot scientific topics such as artificial intelligence, the Internet of Things, virtual reality, and providing an ambitious interpretation of digital skills, while it could be argued that it should be focused on general user skills and competences.

A COMPARISON

In Table 3, the main core areas of the three reference frameworks are given each in a separate column for comparison purposes.

Table 3: Comparison between Digital Competence Frameworks.

UK essential digital skills	Italian PA syllabus	DigComp framework 2.0
Digital foundation skills		
Communicating	Communication and sharing	Communication and collaboration
Handling information and content	Data, information and digital documents	Information and data literacy Digital content creation
Transacting	Online services	
Problem solving		Problem solving
Being safe and legal online	Safety	Safety
	Digital transformation	

The table highlights the fact that there are considerable similarities in terms of structure and content. Indeed, it can be argued there is more or less a common viewpoint across Europe in describing the digital skills every citizen must possess.

The main tool used in the EU to track the progress of digital transformation in society is the Digital Economy and Society Index (DESI). … We argue DESI is not measuring the right set of competencies for the desired goal, that is, a society capable to control the course of its development and progress in the digital world.

An observation could be made that the topic of digital skills and the topic of informatics could be viewed as a continuum with the line of demarcation being drawn differently in the various frameworks.

THE DESI FRAMEWORK

The main tool used in the EU to track the progress of digital transformation in society is the Digital Economy and Society Index (DESI). Each year, the EU measures the various European countries in their progress toward digitalization using DESI. As we will argue, DESI is not measuring the right set of competencies for the desired goal, that is, a society capable to control the course of its development and progress in the digital world. However, these evaluations receive considerable political attention and are used to shape national intervention measures. They currently have an even greater relevance, given the large investments focusing on digital transformation projects in the Recovery and Resilience Plans of EU member states [11]. That is why we analyze in detail the problems with DESI. Later, we argue the need for an approach that is more focused on measuring the right set of competencies.

DESI covers four areas (or dimensions): human capital, connectivity, integration of digital technology, and digital public services. The index therefore has four components or indicators, all considered with equal weight. The one of interest for this discussion is human capital, which aims to measure the preparedness of people to thrive in a digital society. The human capital dimension of DESI is made up by two sub-dimensions, namely "Internet user skills" and "Advanced skills and development," with equal weight [5].

Table 4 shows the actual indicators used to measure the level of people's preparation in these two sub-dimensions. Indicators in bold are considered as having higher importance, since they are particularly relevant for the 2030 Digital Compass strategy, hence their weight within the sub-dimension is twice the others, resulting in the relative weight shown in brackets

Table 4: Indicators used for the Human Capital dimension.

Sub-dimension	Indicator
1a. Internet user skills	1a1. At least basic digital skills (25%) 1a2. Above basic digital skills (25%) **1a3. At least basic digital content creation skills (50%)**
1b. Advanced skills and development	**1b1. ICT specialists (33.3%)** **1b2. ICT female specialists (33.3%)** 1b3. Enterprises providing ICT training (16.7%) 1b4 ICT graduates (16.7%)

No framework exists to measure the status quo of informatics competence development in society, nor in school, even if some digital frameworks have, inappropriately, some measure of some informatics skills.

Since the focus here is school education, which equally affects all citizens, no consideration is given to the second sub-dimension and the focus is on the first one. Its indicators are computed as the percentage of individuals (indicators are computed for each country) having the property specified by the indicator itself.

For this purpose, these indicators rely on the five areas of the Digital Competence Framework 2.0 (DigComp), described previously, used to produce the so-called Digital Skill Indicator (DSI), which "mainly reflects the focus on skills … not on the components of knowledge;" see [20].

THE DIGITAL SKILLS INDICATOR

DSI is built through data collected in each country by means of the "EU Survey on the use of ICT in Households and by Individuals," which contains a broad set of questions on activities related to the five areas of DigComp which are carried out on the internet or related to software use in the last three or 12 months by individuals between the ages of 16 and 74.

Here, we note the definition for each of these five areas (in italics) in DigComp 2.0 and then describe the actual activities investigated in the survey.

Information and data literacy: *To articulate information needs, to locate and retrieve digital data, information and content. To judge the relevance of the source and its content. To store, manage, organise digital data, information and content.*

Activities measured: (i1) Finding information about goods or services; (i2) Seeking health-related information; (i3) Reading online news sites, newspapers or news magazines; (i4) Activities related to fact-checking online information and its sources.

Communication and collaboration: *To interact, communicate and collaborate through digital technologies while being aware of cultural and generational diversity. To participate in society through public and private digital services and participatory citizenship. To manage one's digital identity and reputation.*

Activities measured: (c1) Sending/receiving email; (c2) Telephoning/video calls over the internet; (c3) Instant messaging; (c4) Participating in social networks; (c5) Expressing opinions on civic or political issues on websites or in social media; (c6) Taking part in online consultations or voting to define civic or political issues.

Digital content creation: *To create and edit digital content. To improve and integrate information and content into an existing body of knowledge while understanding how copyright and licences are to be applied. To know how to give understandable instructions for a computer system.*

Activities measured: (d1) Using word processing software; (d2) Using spreadsheet software; (d3) Editing photos, video or audio files; (d4) Copying or moving files (such as documents, data, images, video) between folders, devices (via email, instant messaging, USB, cable) or on the cloud; (d5) Creating files (such as documents, image, videos) incorporating several elements such as text, picture, table, chart, animation or sound; (d6) Using advanced features of spreadsheet software (functions, formulas, macros and other developer functions) to organize, analyze, structure or modify data; (d7) Writing code in a programming language.

Safety: *To protect devices, content, personal data and privacy in digital environments. To protect physical and psychological health, and to be aware of digital technologies for social well-being and social inclusion. To be aware of the environmental impact of digital technologies and their use.*

Activities measured: (s1) Managing access to own personal data by checking that the website where the respondent provided personal data was secure; (s2) Managing access to own personal data by reading privacy statements before providing personal data; (s3) Managing access to own personal data by restricting or refusing access to own geographical location; (s4) Managing access to own personal data by limiting access to profile or content on social networking sites or shared online storage; (s5) Managing access to own personal data by refusing allowing use of personal data for advertising purposes; (s6) Changing settings in own Internet browser to prevent or limit cookies on any of the respondent devices.

Problem solving: *To identify needs and problems, and to resolve conceptual problems and problem situations in digital* *environments. To use digital tools to innovate processes and products. To keep up-to-date with the digital evolution.*

Activities measured: (p1) Downloading or installing software or apps; (p2) Changing settings of software, app or device; (p3) Online purchases (in the last 12 months); (p4) Selling online; (p5) Used online learning resources; (p6) Internet banking; (p7) Looking for a job or sending a job application.

In Table 5, we show how the activities measured in the survey contribute to evaluating the 21 competences articulating the five areas of DigComp [6].

First, only 12 of the 21 competences are covered, meaning 43% of them are not evaluated at all. Second, the measured activities gauge only the skill component while the knowledge component is missing. Third, for some competences the correspondence between the concept alluded to by the competence definition and the actual activities measured appear to be rather weak. As an example, consider competence 3.1 concerning the development of digital content, which is measured by the simple facts of having used a word processor or a spreadsheet or having copied files between devices. Finally, the area of digital content creation lists the competence 3.4 "Programming," which is one of the main components of the scientific discipline of informatics and whose presence in the DigComp framework for citizens appears to be out of scope.

COMPUTING THE INDICATORS FOR HUMAN CAPITAL DIMENSION

For any given answer to the survey, a synthetic indicator for each of the five areas, with value "none," "basic," and "above basics," is computed depending on the fact that the individual has carried out, respectively, none of the measured activities, exactly one, or at least two.

Then the value of an overall indicator for the answer is computed as follows: "above basics" if it is "above basics" in all of the five areas, "basics" if it is not "above basics" in all of the five areas but it is at least "basics" in all of them.

Finally, indicator 1a1 is the percentage of answers with an overall indicator value of "basics," indicator 1a2 is the percentage of those having an overall indicator "above basics." For indicator 1a3 the sum of percentages of "basics" and "above basics" in the third area of DigComp (Digital Content Creation) is used.

The sum of these indicators 1a1, 1a2, and 1a3, weighted according to what is shown in Table 4, provides the final value for the sub-dimension "Internet user skills."

REFLECTIONS

While the sub-dimension "Advanced skills and development" of DESI's Human Capital dimension is clearly adequate, given it is mainly based on the number and percentages of ICT graduates, the analysis presented previously regarding how indicators for "Internet user skills" are based on measuring operational activities (like sending/receiving email, using word processing software, or downloading/installing software/apps), shows that what is measured is not exactly what Europe needs to enable the uptake of digital solutions in business and to increase its competitiveness in the global digital market. Readers should recall the citation from Vuorikar et al. [20] noting the indicators used to produce the DSI "mainly reflects the focus on skills … not on the components of knowledge."

The main argument is that the latter sub-dimension is based on a framework focused on operational skills and a measure using operational skills. These are of course important and necessary in a digital society, but they are not enough to build a really competitive digital society. Even if all indicators 1a1, 1a2, and 1a3

Table 5: DigComp competences and activities measuring them.

Competence	Activities
1.1 Browsing, searching and filtering data, information and digital content	i1, i2, i3
1.2 Evaluating data, information and digital content	i4
1.3 Managing data, information and digital content	---
2.1 Interacting through digital technologies	c1, c2, c3
2.2 Sharing through digital technologies	c4
2.3 Engaging in citizenship through digital technologies	c5, c6
2.4 Collaborating through digital technologies	---
2.5 Netiquette	---
2.6 Managing digital identity	---
3.1 Developing digital content	d1, d2, d3, d4
3.2 Integrating and re-elaborating digital content	d5, d6
3.3 Copyright and licences	---
3.4 Programming	d7
4.1 Protecting devices	s1
4.2 Protecting personal data and privacy	s2, s3, s4, s5, s6
4.3 Protecting health and well-being	---
4.4 Protecting the environment	---
5.1 Solving technical problems	p1
5.2 Identifying needs and technological responses	p2, p3, p4, p5, p6, p7
5.3 Creatively using digital technologies	---
5.4 Identifying digital competence gaps	---

yielded a value of 100% in all EU countries, given the way they are measured, this level of operational skills would be far from sufficient to sustain and promote the digital transformation.

CONCLUDING REMARKS

The need for a distinction between digital skills and informatics has been emphasized. Digital skills are concerned with the ability to competently use digital technology as a provided black-box technology, e.g., email, internet search, word processing. Informatics is about the fundamental concepts and ideas underlying digital technology and the computational revolution, e.g., data, algorithms, programming, design and development, modelling and simulation, security, responsibility, and empowerment. At the same time, informatics is the science and the language behind the digital revolution. Many countries have developed digital competence frameworks and the EU has developed and over the years refined their Digital Competence (DigComp) Framework, which is the basis on which the DESI framework measures the progress of digital competence in society across EU countries. Similarly, many countries have developed (and implemented) curricula in informatics, and there exists a European Informatics Reference Framework for School, which suggests a high-level coherent vision and shared terminology related to providing informatics to all pupils in Europe [2].

However, no framework exists to measure the status quo of informatics competence development in society, nor in school, even if some digital frameworks have, inappropriately, some measure of some informatics skills (e.g., programming).

For this purpose, we have shown—in detailed analysis—that the DESI framework is inadequate. We therefore conclude that there is a need for an informatics measurement framework to provide an informatics competence indicator, which will complement the DESI framework. Such a framework is needed to measure the status quo and thus track progress of informatics competence development both in school and in society in general. This is echoed in the European Commission's recent "Proposal for a Council Recommendation on improving the provision of digital skills in education and training" where it says: *"... support quality education in informatics by developing common guidelines for teachers and educators to foster quality education in informatics and developing informatics competence indicators, in line with existing competence and curricular frameworks"* [9]. We also add that the Staff Working Document accompanying this Proposal explicitly recognizes the need for a new approach: *"It is internationally recognised that there is a fast emerging trend in educational systems to include Informatics as part of national curricula and as part of the general education for all. ... For some time, most European educational systems fell behind this trend, focusing more on digital literacy and with the digitalisation of teaching. The main limitation of this approach is that, despite providing pupils the means to use digital technologies, it does not fully equip them with the ability to create, control and develop digital content"* [10, p.87]. ❖

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Andrew McGettrick
Professor Emeritus
Computer and Information Sciences
University of Strathclyde
Glasgow, Scotland, UK
andrew.mcgettrick@strath.ac.uk

Michael E. Caspersen
Honorary Professor
Department of Computer Science
Aarhus University
Aarhus, Denmark
mec@it-vest.dk

Judith Gal-Ezer
Professor Emerita of Computer Science
Open University
Tel Aviv, Israel
galezer@openu.ac.il

Enrico Nardelli
Professor of Informatics
University of Rome Tor Vergara
Rome, Italy
nardelli@mat.uniroma2.it

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