**Exploring the Construct of the New Way of Thinking in the Digital Environment**

**Abstract**

The aim of this study is to provide insights concerning the effects of the ubiquitous digital environment on the way people think and the subsequent need to equip young individuals with the necessary skills. Several studies focus on defining the so-called digital skills, also providing indications that higher cognitive skills are required. However, they do not examine how young individuals could perform better to adapt to the continuously evolving digital environment. To address this gap, the study introduces and analyzes the construct of digital intelligence, representing the new way of thinking and behaviour in the digital environment. For the purposes of the study, a set of tests was given to students at Greek high schools, targeting 15-16 years old students and employing original tests to assess digital intelligence. According to the findings, digital intelligence is composed of: 1) logical reasoning, algorithms, and evaluation, 2) abstraction, decomposition, and patterns and generalization, 3) digital emotional intelligence and communication, 4) digital safety and security, and 5) digital identity, use, literacy, and rights. Assessing digital intelligence, as proposed in this study, could be used to assist vocational guidance, employee selection and evaluation, and development of revised school curricula.

**Keywords**

Digital intelligence

Digital skills

Digital competence

Digital environment

Computational thinking

Digital use and behaviour

# Introduction

The extensive use of Information and Communication Technologies (ICTs) and particularly the emerging digital technologies, that nowadays have become ubiquitous, smart, and invisible, have introduced significant changes to businesses, as well as people’s lives. Exploring how digital technologies affect daily human activities, several classifications have been used to characterise people based on the differences in technology access. Prensky (2001) proposed a distinction of people into “digital natives” and “digital immigrants”. He claimed that whoever belongs to the first category thinks and processes information fundamentally differently from others. Tapscott (2008) named the people who grew up and were educated at about the time of the Internet’s advent, the “Net Generation” (also called Generation Y) and the children who were born afterwards, the “Generation Next” (also called Generation Z). According to Tapscott, people of the Net Generation and the Generation Next show signs of learning differently. He also said that it is the first time in history that children are more knowledgeable and literate than their parents. An interesting aspect that literature suggests, is that several cognitive abilities are quite different in the digital and the physical environment. Carr (2008, 2010) pointed out that we do not think nowadays the way we used to think. In the same vein, Nicholas, Huntington, Williams, and Dobrowolski (2004) noted that the Internet has given birth to a new cognitive model of obtaining knowledge.

Within this context, a great effort has been made by governments and organizations to identify the essential skills and competences that people need to acquire in order to “live” and “operate” successfully, while using digital devices and media effectively. The focus is therefore on specific abilities as an outcome of educational and learning procedures. However, the emerging digital environment may require more than that, raising issues of identifying people’s ability to adapt in the digital era despite their acquired skills. In our view, this gap can be confronted by the construct of “digital intelligence”, as proposed in this paper. Adams (2004) first used that term to describe the effects of digital technology in people’s lives and the changes made in communication, lifestyle, economic practices, as well as the way of thinking.

According to the current study, “digital intelligence” represents the new way of thinking that people develop in the digital environment, which seems to embrace elements of computational thinking, and digital use and behaviour. In the context of that, the paper reviews the literature on computational thinking, mainly based on Wing’s (2006, 2008) research, and digital use and behaviour framework, to propose a unified set of elements for digital intelligence. The structure of the paper is as follows: the main characteristics of the digital environment are outlined in Section 2.1. The theoretical justification of the current research concerning the new way of thinking is discussed in Section 2.2, leading to the construct of digital intelligence in Section 2.3. Section 2.4 presents the research questions resulting from the literature review and Section 3 presents the methodological approach of the study. The results are given in Section 4, while discussion and conclusions are summarized in Sections 5 and 6, respectively.

1. **Theoretical background**

# *Characteristics of the digital environment*

The digital environment is much more than just using digital devices and media. Whereas the impact of digitization on everyday life began by the extensive use of ICTs, the advent of the Internet and its fast penetration posed new challenges to ICT performance. Moreover, the great increase of the Internet penetration has been leveraged by the widespread use of the mobile Internet. Figure 1 illustrates the rapid growth in individuals’ Internet usage, while Figure 2 presents the growth in active mobile-broadband subscriptions.

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|  |  |
| **Figure 1.** Global numbers of individuals using the Internet, total and per 100 inhabitants, 2001-2019\* |  | **Figure 2.** Active mobile-broadband subscriptions per 100 inhabitants, 2007-2019\* |
| *Note: \* Estimate, Source: ITU* |  |  |

According to International Telecommunication Union (ITU 2019), 4.1 billion people were using the Internet in 2019, reflecting a 5.3 percent increase compared with 2018, while the global penetration rate increased from nearly 17 percent in 2005 to over 53 percent in 2019. Concerning the mobile Internet usage, the number of active mobile broadband subscriptions per 100 inhabitants continues to grow strongly, with an 18.4 percent year-on-year growth. ITU also found that before the rise of smartphones, there were virtually no countries where more households had Internet access at home than computers, a reality that now has changed. In recent years, more households in many countries have Internet access than computers, since computers are no longer necessary to connect to the Internet, and many people connect by using devices such as smartphones, being the preferred access path; this change in access has gone along with an expansion of the mobile-cellular network, which now covers almost the entire world population, since 82 percent live within reach of an LTE or higher mobile-broadband signal, and another 11 percent have access to a 3G network (ITU 2019). Therefore, it could be said that the mobile Internet is a driving force in shaping the digital environment, since Internet access becomes ubiquitous, independently of fixed PC connection, providing real time data and information.

In addition, massive production of “smart” devices, widespread use of cloud computing, sensors’ monitoring, and big data analysis consist some of the main drivers of the digital transformation. Ubiquitous computing and connectivity are the principal characteristics of those technologies, reshaping the world from “physical” to “digital” (Accenture 2017). Moreover, examples of everyday life are remarkable. When approaching a physical retail store, customised advertisements of the store are sent in real time to the customer’s smartphone, due to Location Based Services (Bridwell and Miller 2016); supermarkets will soon use applications to directly update inventory levels immediately after picking the product, altering marketing and supply chain implementation; smart watches provide real time biometric data, etc. Marketing also becomes personalized, raising legal issues of handling individuals’ personal data and online behaviour at the same time. In addition, people are literally working virtually using mobile devices, connected 24 hours per day. In short, it can be concluded that whereas the “digital environment” has been present since the advent of ICT many decades ago, nowadays it is much more intense, as it has become ubiquitous, smart, and invisible, while becoming an integral part of our lives.

# *The new way of thinking*

The multiple effects of the emerging digital environment on every aspect of human life and behaviour seem to influence the way we think nowadays. The relevant literature mentions that several cognitive abilities are quite different in the digital and physical environment, altering broadly the process of thinking. People’s reading behaviour is different in the digital environment compared to the physical one, since readers devote much less time on in-depth and concentrated reading of electronic documents, mainly due to the existence of hyperlinks in a document (Liu 2005). Carr (2010) pointed out that this constant disruption, which is more intense when someone is online, prevents the human brain to create neural connections for deep thinking. Moreover, according to Kress (2003), multimodality of electronic documents (images, audio, video, text, etc.) changes the way that readers perceive and understand them (firstly, as a large mass of shape and colour, then selecting information from images and videos, and finally reading specific words and phrases). Kress also argues that this dominating form of enhanced information will affect human cognition and forms of knowledge.

In addition, it was pointed out that video games develop visual skills to a significant extent, but at the expense of other skills, such as critical thinking and imagination (Greenfield 2009). Greenfield also argued that video games and the Internet are producing learners with a new profile of cognitive skills. Regarding video games, Homer, Plass, Raffaele, Ober, and Ali (2018) claimed that they improve high school students’ executive functions, i.e. the skills required to plan, monitor, and control cognitive processes. In the same vein, Ott and Pozzi (2012) suggest that digital educational tools may contribute to the increase of a child’s creativity. According to Bowman, Levine, Waite, and Gendron (2010), communication differs in the digital environment since users of digital media have the time to compose and revise their responses and this gives them more control over their communication. Barr, Pennycook, Stolz, and Fugelsang (2015) found that the extensive use of smartphones via mobile Internet connection affects human cognition, as people allocate the thinking process to smartphones.

Moreover, it is particularly important that advanced users of digital media develop an algorithmic way of thinking (Shaffer and Clinton 2006), while new ways of learning to do things are established in the digital environment making the traditional means obsolete (Prensky 2001; Tapscott 2008). Wolf and Barzillai (2009) also stated that media or other technologies used in learning and practicing the craft of reading play an important part even in shaping the neural circuits inside the brain. The circuits woven when using the Internet will be different from those woven when reading printed works, as neuroimaging investigations have suggested (Loh and Kanai 2015). Athreya and Mouza (2017) concluded that, “in this era of information over-abundance and sophisticated technologies, we need to hone our thinking skills more than ever” (p. 145). They also argue on whether the Internet may have long term effects on thinking, as there are no sufficient studies yet, although they present evidence on the effect of technology on human cognitive capabilities.

The aforementioned review reveals that cognitive processes are performed differently in the digital era and could be regarded as an indication, either that a new way of thinking has started to emerge or that people need to develop a new way of thinking in order to adapt to the digital environment. Besides, as McLuhan (1964) pointed out, media are not just passive channels of information, but they shape the process of thought. This statement remains highly topical in today’s intense digital environment. Table 1 provides a summary of the main differences in cognitive processes spotted in the digital environment (Stiakakis, Liapis, and Vlachopoulou 2019), as well as the effects and implications on cognition.

**Table 1.** Cognitive processes in the digital environment

|  |  |  |
| --- | --- | --- |
| Tasks/processes in the digital environment | Effects and implications on cognition  | Reference |
| Selective, one-time, non-linear reading of electronic documents | Screen-based reading behaviour characterized by abstraction and distraction of attention  | Carr (2008); Liu (2005); Wolf (2009, 2018); Baron (2017) |
| Screen reading (viewing screens, scrolling and/or misplaced digital reading habits) | Reading competence is performed better on a reading test presented on paper than on screen even for children familiar to digital media | Støle, Mangen, and Schwippert (2020) |
| Digital reading (flashanimations, app books, and augmented reality (AR) books) | Children become more interested in storybooks, but their reading concentration is significantly decreased | Wang, Lee, and Ju (2019) |
| Random access to information. Receiving information really fast from many sources at the same time (multimodality of electronic documents, hypertext links and browser functions) | New information seeking behaviour based on multitasking and real time thinking | Kress (2003); Prensky (2001) |
| Enhanced informal learning environments (television, video games, Internet, etc.) | New informal learning environments pose challenges to formal education. Developing critical thinking is vital to face the new learning requirements | Greenfield (2009) |
| Extensive use of action video games | Video games improve many cognitive abilities, such as reasoning, receptive vocabulary, visual short-term memory, and processing speed | Homer et al. (2018); Gnambs and Appel (2017); Dobrowolski, Hanusz, Sobczyk, Skorko, and Wiatrow (2015) |
| Handwriting has switched from pen and paper to mouse, keyboard, and screen | Writing with digital devices detaches visual attention from the input of characters posing difficulties to memorization | Mangen and Velay (2010) |
| Digital storytelling techniques in education (combining telling stories with a variety of multimedia, including graphics, audio, video, and Web publishing) | Digital storytelling affects positively the visual memory capacity and writing skills of primary school students  | Sarıca and Usluel (2016) |
| People must process large number of simultaneous stimuli of different kinds (e.g. sound, text, images) | Need for real-time thinking ability | Eshet (2012) |
| Information seeking is a continuous process | New information seeking behaviour | Nicholas, Huntington, Williams, and Dobrowolski (2004) |
| Children want to seek information in groups, and they like to share it with others | Communication attitude based on “knowing together” | Dresang (2005) |
| Excessive use of instant messaging and other digital media (e.g. email, blogs, fora), where users have the time to compose and revise their responses | Getting more control over communication | Madell and Muncer (2007); Bowman et al. (2010) |
| Excessive use of mobile social networking sites | Leading to addictive behaviour | Gong, Yu, and Luqman (2019) |
| Usually people do different things simultaneously, as for instance, during a video game | Need for ability to multitasking | Eshet-Alkalai (2004); Wolf and Barzillai (2009); Greenfield (2009) |
| New computational tools problematize the concept of thought within current sociocultural theories of technology and cognition | It is possible for the user of digital media to externalize a particular form of thinking, namely algorithmic thinking | Shaffer and Clinton (2006) |
| New ways of learning to do things (e.g. through computer games, simulation) | Acquisition of knowledge is getting more experiential | Prensky (2001); Tapscott (2008) |

Apart from the above processes and characteristics that are cited in the literature, there are also several experiential differences from various daily activities or habits that are worth mentioning, as shown in Table 2 (Stiakakis et al. 2019). They are indicative of the different way of thinking in the two environments, revealing new forms of using digital media and new types of attitude in the digital era.

**Table 2.** Indicative experiential differences for various daily activities between the digital and the physical environment

|  |  |
| --- | --- |
| Physical environment | Digital environment |
| Taking notes on paper | Taking notes on a mobile device or taking a picture of notes by using the smartphone |
| Seeking information through print media or by going to a library (especially for scientific information) | Seeking information by using a search engine, such as Google |
| Trying to orientate by asking others for locations | Using online maps, such as Google maps |
| Looking at our wristwatch when we want to see what time it is | Looking at our mobile phone’s screen even though we are wearing wristwatches |
| Looking at signs about the departure and arrival time when using transportation means | Being notified by using mobile apps |
| Comparing product prices by going shopping or using catalogues | Comparing product prices on the Internet |
| Ordering (e.g. food) via phone | Ordering through the Internet |
| Doing calculations when paying with cash | No need to do calculations when using e-payment methods (e.g. smart cards, e-banking) |
| Describing an event (e.g. a concert) | Enriching the description with digital media (e.g. video on our smartphone) |
| Telling a story to our friends | Sharing the story (usually by uploading a picture or video) on social media |
| Watching news on TV | Following news websites via social media platforms and Web browsers |
| Learning to do things by using manuals | Learning to do things by watching online videos (e.g. YouTube) |
| Waiting to listen again a nice song that we do not know its title | Finding out a song by typing a phrase on online sharing video services (e.g. YouTube) or using a suitable app to detect (via spectrograms) |
| Interacting in face-to-face meetings / conferences | Online meetings / video conferencing  |
| People use physical / verbal violence to harm vulnerable population groups | Online approach / new forms of cyber threats (i.e. cyberbullying) |
| Technical security requirements when using plain electronic devices  | Extensive safety and security issues in on-line environments to be protected from cyber threats |

The main characteristics of the cognitive processes in the digital environment, as have previously been presented, can be summarized as follows:

* Information access in the digital environment is random.
* The digital environment demands real-time thinking, processing a large number of simultaneous stimuli of different kinds, which is often disruptive.
* Different things are done simultaneously (multitasking).
* It is possible for the user of digital devices and media to externalize a particular form of thinking, namely algorithmic thinking.
* Experience reveals an emerging type of users’ attitude and behaviour that is developing in the digital environment.
* New technologies and applications demand new rules of usage, especially in terms of safety and security.

Consequently, the literature review, as well as examples of everyday life, imply that the extensive use of digital devices and media in the ubiquitous digital environment leads to the development of a new way of thinking, which mainly embraces elements of algorithmic thinking, behaviour towards digital technology, and usage of digital devices and media.

# *The construct of digital intelligence*

Within this context, the challenge is how to adapt to the emerging digital environment and the subsequent new way of thinking. Relative studies, so far, have focused on identifying the essential skills (i.e. digital skills) that people need to acquire in order to “live” and “operate” successfully in the digital environment. Skills, though, refer to specific abilities that can be acquired through education, training, practice, etc., and assist young people to operate more efficiently in the digital environment. However, adaptation to a new environment is a broader process, which is mainly related to intelligence rather than knowledge acquisition. According to Piaget (1972), adaptation to the environment is the most important principle of intelligence. Moreover, Sternberg (2012) states that intelligence is the ability to adapt to the environment, shape it (with the meaning of change) or select a new environment. It should also be pointed out that, Legg and Hutter (2007) provided an extensive collection of definitions of intelligence; by examining those definitions, it can be deduced that one of the most essential features of intelligence is adaptation to the environment.

One of the greatest changes is apparently the emergence and growth of the digital environment. Therefore, adaptation to the digital environment could be referred to as “digital intelligence”, representing the new way of thinking in the digital environment, embracing its main characteristics, i.e. algorithmic thinking, behaviour towards digital technology, and usage of digital devices and media. It should be noted, though, that the construct of “digital intelligence”, as used for the purposes of this study, does not constitute a new form of intelligence, as this is out of the scope of the paper.

According to Denning (2009), “algorithmic thinking” was initially used in computer science; however, it has expanded to “computational thinking” (CT), which is a broader concept that goes beyond computation and computer science. Specifically, CT as introduced by Wing (2006), describes a way of thinking to confront complex problems and situations. Such complexity is commonly faced in the digital environment, as, for instance, through multitasking and real time thinking, and in processing of a large number of simultaneous stimuli of different kinds. CT is regarded as an important competence for individuals in today’s digital environment (Yadav, Good, Voogt, and Fisser 2017). However, as stated in Section 2.2, this is one part of digital intelligence. Nowadays, there is a growing concern for behavioural, ethical, and usage issues about technology, that differ from technical and computational aspects. The ubiquitous digital technologies raise issues, such as discrimination, autonomy, human dignity, and unequal balance of power, that go beyond privacy and data protection (Royakkers, Jelte, Timmer, Kool, and van Est Such 2018). Moreover, Royakkers et al. (2018) pointed out that the governance system has failed to respond effectively to those implications of technology, since they are not clearly understandable yet. In the same vein, DQ Institute (2019) acknowledged similar impacts of today’s technological advances, particularly in children, and developed a framework to equip young people with the necessary skills to become ethical and discerning digital citizens.

* + 1. *Computational Thinking*

Wing (2006) introduced the concept of computational thinking (CT) as dealing with a problem in a way that a computer can help us to solve it. She believes that it is a fundamental skill for everyone, not just for computer scientists and should be added to children’s abilities. Computational thinking is a kind of analytical thinking, which shares with mathematical thinking, engineering thinking, and scientific thinking. Wing (2011) proposed a new definition of CT: “Computational thinking is the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent” (p. 1). According to this definition, CT is a thought process, thus independent from technology, a problem-solving methodology that expands the realm of computer science into all disciplines.

The concept posed new educational challenges for our society, especially for children. Several countries have concluded with a process of curriculum renewal that has boosted the teaching of CT and related concepts in compulsory education. England (UK) has been acknowledged as a pioneer (Bocconi, Chioccariello, Dettori, Ferrari, and Engelhardt 2016), being one of the first European countries to mandate CT and coding in primary and secondary schools. The Department for Education UK (2013) adopted the concept to develop programmes of study in a four-stage approach in the learning process. Various researchers proposed different elements of CT, similar to one another (Bocconi et al. 2016). According to the Department for Education UK (2013) and Computing at School (2015), CT involves the following six (6) concepts:

* Logical reasoning: predicting the behaviour of a computer program (e.g. what will happen when playing a computer game or using a simple program) – explaining how the program works.
* Algorithms: realizing how algorithms are used in computer programs – writing down the algorithm for a program (e.g. using pseudocode or flow charts) – finding the quickest way to achieve the goal of the program.
* Decomposition: breaking down a problem into smaller manageable parts – thinking about how these parts are inter-related.
* Abstraction: capturing key information and removing unnecessary details from the system or problem under study.
* Patterns and generalization: identifying patterns in a problem – looking for a general approach to solve a number of problems.
* Evaluation: assessment of data and information – making judgements for the most effective and efficient solution, using skills such as testing, tracing, and logical thinking to predict and verify outcomes.
	+ 1. *Digital Use and Behaviour*

Digital use and behaviour constitutes the main pillar of the “Digital Intelligence Quotient”, a construct developed by DQ Institute. According to DQ Institute (2019), “digital intelligence is a comprehensive set of technical, cognitive, meta-cognitive, and socio-emotional competences that are grounded in universal moral values and that enable individuals to face the challenges and harness the opportunities of digital life and adapt to its demands” (p. 8). DQ Institute reviews current proposed frameworks worldwide and identifies eight digital competences that individuals should develop, divided into three distinct levels (digital citizenship-creativity-competitiveness), according to their progress in adopting and understanding technologies in their life. Since our study focuses on early ages (i.e. Digital Citizenship: the ability to use digital technology and media in safe, responsible, and ethical ways), the DQ competences can be summarised as follows:

* Digital identity: the ability to build and manage a “healthy” online and offline identity as a digital citizen with integrity; demonstrate ethical and considerate behaviour and netiquette when using technology; understand the construction of their online personality, as well as the impact that technology may have on their self-image and values.
* Digital use: the ability to use technology in a balanced, healthy, and civic way; understand the nature and impact of technology use on health, work productivity, well-being, and lifestyles; exhibit integrity and develop positive relationships with others through the rational use of technology.
* Digital safety: the ability to understand, mitigate, and manage various cyber risks (e.g. cyberbullying, harassment, and stalking) that relate to personal online behaviours through safe, responsible, and ethical use of technology.
* Digital security: the ability to detect, avoid, and manage different levels of cyber threats to protect personal data, devices, networks, and systems.
* Digital emotional intelligence: the ability to recognize and be supportive of one’s own and other’s feelings, needs and concerns online, and express emotions in one’s digital intra and interpersonal interactions.
* Digital communication: the ability to communicate and collaborate with others using digital technology and responsibly manage digital footprints.
* Digital literacy: the ability to find, read, synthesize, create, share, and evaluate media and online information, with critical reasoning, assessing reliability and credibility of online information.
* Digital rights: the ability to handle all personal information shared online with discretion, understand privacy as a human right, understand and uphold human rights and legal rights when using technology as digital citizens.
	+ 1. *Digital Intelligence*

Wing’s computational thinking concept focuses on the need for developing a computer-based process to deal with problems, without reviewing digital use and behaviour issues. On the other hand, DQ Institute follows a skill-based approach to define the necessary competences in the digital era, focusing on developing citizens with the ability to use digital technologies and behave properly in the digital environment, without including elements of thinking.

Digitally intelligent individuals, however, as the review in Section 2.2 implies, have all the above three characteristics: a) they have the ability to use digital technology properly, b) they can understand and develop proper online behaviour, and (c) they are able to face complex problems in the digital environment. The first two elements constitute “digital use and behaviour”, whereas the third reflects “computational thinking”.

Therefore, it can be concluded that the construct of “Digital Intelligence” (DI), representing the new way of thinking in the digital environment, is composed of: (i) “computational thinking” (CT) and (ii) “digital use and behaviour” (DUB), and subsequently comprises the fourteen elements of CT and DUB, as shown in Figure 3.



**Figure 3.** The construct of Digital Intelligence (DI)

* 1. *Research Questions*

The construct of DI, as Figure 3 depicts, can be broken down into fourteen elements. However, their analysis, provided in Sections 2.3.2 and 2.3.3, shows that some of them have similar traits. Moreover, without a comprehensive understanding of the elements that constitute DI, it would be difficult to assess the usefulness and importance of the construct. Thus, our objective is to investigate the following research questions:

* RQ1: Can the fourteen (14) elements of DI be categorised into distinct groups?
* RQ2: How are these possible emerging groups related to DI?

# Methodology

To examine the research questions, an online set of tests were taken by students at the age of 15-16 years old in senior high schools (first year students at a senior high school according to the Greek educational system). For the purposes of this process, permission was requested and given from the Hellenic Institute of Educational Policy.

* 1. *Sampling and participants*

The sample of the study is composed of public senior high schools in the Regional Unit of Thessaloniki, which is the second biggest Regional Unit in Greece in terms of population. The Regional Unit of Thessaloniki is subdivided into 14 municipalities: (i) Ampelokipoi-Menemeni, (ii) Chalkidona, (iii) Delta, (iv) Kalamaria, (v) Kordelio-Evosmos, (vi) Langadas, (vii) Neapoli-Sykies, (viii) Oraiokastro, (ix) Pavlos Melas, (x) Pylaia-Chortiatis, (xi) Thermaikos, (xii) Thermi, (xiii) Thessaloniki, and (xiv) Volvi. To ensure a reliable sample of schools, an effort has been made to use the same sample that had been used in a study conducted by the PISA[[1]](#footnote-1).

PISA is the OECD’s[[2]](#footnote-2) programme for international student assessment. It measures 15-year-olds’ ability to use their reading, mathematics, and science knowledge and skills to meet real-life challenges. PISA schools were sampled systematically from a comprehensive national list of all PISA-eligible schools, known as the school sampling frame, with probabilities that were proportional to a measure of size. Thus, it was considered that for the scope of the current research it would be more accurate to follow the same sample used in PISA’s survey, ensuring the validity of our testing sample.

For all the municipalities, the target was to have a greater or at least equal sample than the one used in the PISA survey. To achieve that, 35 senior high schools (27 general and 8 vocational) were selected to participate. Finally, 21 senior high schools (14 general and 7 vocational) responded. Data for the selection of the schools participating in the sample are presented in Table 3.

**Table 3.** Sampling of schools per municipality

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| No | Municipality | Population | Senior high schools | Proposed schools in our sample | Sample% | Respondent schools to the survey | Sample% |
| 1 | Ampelokipoi-Menemeni | 52,127 | 6 | 1 | 16.7% | 1 | 16.7% |
| 2 | Chalkidona | 33,673 | 8 | 2 | 25.0% | 0 | 0.0% |
| 3 | Delta | 45,839 | 7 | 2 | 28.6% | 2 | 28.6% |
| 4 | Kalamaria | 91,518 | 8 | 2 | 25.0% | 2 | 25.0% |
| 5 | Kordelio-Evosmos | 101,753 | 9 | 3 | 33.3% | 0 | 0.0% |
| 6 | Langadas | 41,103 | 6 | 1 | 16.7% | 0 | 0.0% |
| 7 | Neapoli-Sykies | 84,741 | 7 | 3 | 42.9% | 1 | 14.3% |
| 8 | Oraiokastro | 38,317 | 4 | 2 | 50.0% | 2 | 50.0% |
| 9 | Pavlos Melas | 99,245 | 11 | 3 | 27.3% | 3 | 27.3% |
| 10 | Pylaia-Chortiatis | 70,110 | 6 | 3 | 50.0% | 1 | 16.7% |
| 11 | Thermaikos | 50,264 | 5 | 2 | 40.0% | 1 | 20.0% |
| 12 | Thermi | 53,201 | 6 | 2 | 33.3% | 0 | 0.0% |
| 13 | Thessaloniki | 325,182 | 30 | 7 | 23.3% | 6 | 20.0% |
| 14 | Volvi | 23,478 | 4 | 2 | 50.0% | 2 | 50.0% |
|  | *Total* | *1,110,551* | *117* | *35* | *33%* | *21* | *19.2%* |

The testing procedure was conducted at the period from 1/4/2019 up to 17/5/2019 and the sample size in terms of the number of respondent students was 956, 57% males and 43% females. Figure 4 provides information on parental education.



**Figure 4**. The educational level of the respondents’ parents

* 1. *Test design and administration*
		1. *Set of tests*

The research was conducted using an online set of tests that was developed for this scope (see Appendix A). It consisted of three parts: part (A) was about demographic data of the participant students, i.e. gender, municipality of residence, educational level of parents, usage of digital devices, navigation time on the Internet, social media accounts, as well as questions about their perceptions: (i) the courses in which the students think they have the highest performance and (ii) self-assessment of students’ relationship to ICTs. Part B had six (6) tests to assess computational thinking and part C consisted of eight (8) tests to assess digital use and behaviour (the tests of part B and part C were mixed up). It should be noted that some of the tests assess more than one element of CT or DUB, since there are significant similarities between them. However, in these cases the main element that is assessed can be spotted. Table 4 summarizes the elements that each test assesses, stating separately as “primary” the most dominant element of the test. For example, test 3 assesses “rights” and “communication”, however its dominant element is “rights”. This categorisation may also assist in further interpretation of the results.

**Table 4****.** Elements assessed by test

|  |  |  |  |
| --- | --- | --- | --- |
| Test | CT/DUB | Element | Primary Element |
| Test 1 | CT | abstraction | abstraction |
| Test 2 | CT | decomposition & abstraction | decomposition |
| Test 3 | DUB | rights & communication | rights |
| Test 4 | CT | evaluation | evaluation |
| Test 5 | DUB | identity | identity |
| Test 6 | CT | patterns & generalization | patterns & generalization |
| Test 7 | DUB | use | use |
| Test 8 | DUB | safety & emotional intelligence | emotional intelligence |
| Test 9 | CT | logical reasoning & algorithms | logical reasoning |
| Test 10 | CT | algorithms | algorithms |
| Test 11 | DUB | security & rights | security |
| Test 12 | DUB | safety & communication | safety |
| Test 13 | DUB | literacy | literacy |
| Test 14 | DUB | emotional intelligence & communication | communication |

* + 1. *Procedure*

Since there is no similar research in the proposed construct of DI, the tests used are original and have been developed based on the following consistent procedure (Figure 5):

* Tests should not exceed students’ disciplines. Therefore, a thorough review of the senior high school curricula was made to ensure that the tests match the educational level of the participating students.
* Tests should assess students’ cognitive abilities and not their knowledge.
* Tests were developed to meet the characteristics of each of the fourteen elements of CT and DUB, as described in Sections 2.3.2 and 2.3.3.
* Tests should resemble digital environment in terms of information presented.
* Fourteen (14) tests of almost the same difficulty were designed to represent every element and ensure the participants’ ability to take the tests within a teaching hour (45 minutes).
* To review the tests, a panel of experts was used. The panel consisted of two IT teachers in public senior high schools, a member of the Hellenic Institute of Educational Policy, a professor of IT at the University of Macedonia, and a social media developer. The members of the panel revised the tests.
* The revised version was tested in two pilot classes by the senior high school teachers.
* The amendments made were revised once again by the panel of experts to extract the final version of the tests.
* The final set of tests was then developed to a Google form in order to be taken online by the students.

The above procedure and rules have strictly been followed in an effort to establish construct validity. It should be noted that, for tests 4, 6, and 10 concerning evaluation, patterns & generalisation, and algorithms, respectively, existing psychometric tests have been adjusted, as necessary. The others have been developed from scratch, resembling a digital environment as much as possible. For example, test 1 assesses “abstraction” representing a digital screen with various objects that are indirectly related to digital processes; test 3 assesses “rights & communication” simulating a situation where individuals share their status in social networks by using icons and pictures similar to well-known social platforms.



**Figure 5.** The test development process

The overall student performance, called “digital intelligence score” (DI score), was calculated as follows: one point was assigned to every correct answer and zero points to the false ones. For tests 1, 2, and 14, where the participant was required to choose six elements, only the answer, that had at least 5 out of 6 correct choices, was considered to be correct.

* 1. *Data collection and analysis*

Figure 6 presents the correct answers in each of the CT and DUB tests. The data given suggest that students had better performance in the tests that were used for the assessment of digital use and behaviour. This is probably because young people at the age of 15-16 years old are more familiar with the use of digital devices, mostly with smartphones. On the other hand, their performance in computational thinking can be considered quite low.

|  |  |  |
| --- | --- | --- |
|  |  |  |

**Figure 6.** The number of correct answers in the total of the participants for each of the 14 tests

Figures 7 to 12 provide an overview of the research findings. In Figures 7 and 8, the average DI score of the respondent students, in relation to their parents’ educational level, is presented. The average DI score of students increases as the level of education of their parents increases. Figures 9 and 10 depict the average DI score depending on the usage time of digital devices (desktop, laptop, tablet, smartphone, video games console, etc.) and the navigation time on the Internet, respectively. It can be seen that, DI score increases proportionally with the usage time, although more slightly when the time increases significantly. On the other hand, when the navigation time is more than 4 hours, DI score decreases.

The average DI score, in relation to the municipality of residence of the respondent students, is illustrated in Figure 11. The wealthier areas are represented in blue, the areas at a medium level in grey, and the poorer areas in green (the division was based on the average objective value of property of the municipalities). The figure shows that the wealthier municipalities indicate rather low DI scores. The high scores in the municipalities “Thermaikos” and “Oraiokastro” are mainly due to the high educational level of parents, as presented in Figures 7 and 8. Concerning the municipality “Delta”, which has the third highest DI score, the students mostly come from vocational senior high schools, where the course of Informatics (concerning the development of digital skills), is included in the curriculum.

Figure 12 presents the average DI score, in relation to the course (of the school curriculum) in which the students think they have their best performance. The students who selected Science and Mathematics had higher DI scores, while the students who considered that they performed their best in Physical Education scored much lower in DI.

|  |  |
| --- | --- |
| **Figure 7.** Average DI score in relation to father’s educational level | **Figure 8.** Average DI score in relation to mother’s educational level |
| **Figure 9.** Average DI score in relation to usage time of digital devices | **Figure 10.** Average DI score in relation to navigation time on the Internet |
| **Figure 11.** Average DI score in relation to municipality of residence | **Figure 12.** Average DI score in relation to the course with the best performance |

1. **Results**
	1. *Internal consistency*

Considering internal consistency of the scores of the 956 participants in DI tests, Cronbach’s alpha was used. Measured with SPSS, Cronbach’s alpha is 0.793, implying that the measurement scale used in the tests indicates good reliability. It should be noted that, if any of the fourteen sets of scores was deleted, Cronbach’s alpha would decrease, and that entails that all the fourteen tests can be used in the measurement of DI.

* 1. *Answering RQ1*

An exploratory factor analysis (EFA) was employed to test whether the fourteen elements, identified in Section 2.3.3, can be categorized into distinct groups (components). The sample size of 956 students is perfectly acceptable for factor analysis (the minimum sample size is five times the number of variables, i.e. 5x14=70, and an acceptable sample size would be ten times the number of variables, i.e. 10x14=140). The sample is appropriate for factor analysis, if: a) KMO is greater than 0.6 and b) Bartlett’s test is statistically significant. The null hypothesis in Bartlett’s test is that all correlations between the 14 variables equal to zero. In our case, it is rejected (p<0.05) and since KMO>0.6 (Table 5), the sample is appropriate for factor analysis. As shown in Table 6, which presents the correlations between the variables and the components extracted, five components emerged. As we can see, there are five components having eigenvalues greater than 1, which account for 46 percent of the total variance explained. In addition, according to the scree plot criterion (Figure 13), the ‘elbow’ in the curve in the fifth component indicates that five components are extracted. Table 7 illustrates the Rotated Component Matrix. The varimax method, which is the most well-known of the orthogonal factor rotation methods, was used. A perusal of Table 7 reveals that the 14 elements of the construct of digital intelligence are grouped into the following five components: 1) digital communication and digital emotional intelligence, 2) abstraction, decomposition, and patterns and generalization, 3) algorithms, evaluation, and logical reasoning, 4) digital security and digital safety, and 5) digital literacy, digital use, digital rights, and digital identity.

**Table 5.** KMO and Bartlett’s Test

|  |  |
| --- | --- |
| Kaiser-Meyer-Olkin Measure of Sampling Adequacy. | .644 |
| Bartlett’s Test of Sphericity | Approx. Chi-Square | 514.513 |
| df | 91 |
| Sig. | .000 |

**Table 6**. Total Variance Explained

|  |  |  |  |
| --- | --- | --- | --- |
| Component | Initial Eigenvalues | Extraction Sums of Squared Loadings | Rotation Sums of Squared Loadings |
| Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 1,939 | 13,847 | 13,847 | 1,939 | 13,847 | 13,847 | 1,612 | 11,512 | 11,512 |
| 2 | 1,187 | 8,482 | 22,329 | 1,187 | 8,482 | 22,329 | 1,367 | 9,765 | 21,277 |
| 3 | 1,119 | 7,990 | 30,319 | 1,119 | 7,990 | 30,319 | 1,159 | 8,281 | 29,558 |
| 4 | 1,084 | 7,744 | 38,063 | 1,084 | 7,744 | 38,063 | 1,135 | 8,105 | 37,663 |
| 5 | 1,064 | 7,597 | 45,660 | 1,064 | 7,597 | 45,660 | 1,120 | 7,998 | 45,660 |
| 6 | ,988 | 7,059 | 52,719 |  |  |  |  |  |  |
| 7 | ,952 | 6,803 | 59,522 |  |  |  |  |  |  |
| 8 | ,947 | 6,762 | 66,284 |  |  |  |  |  |  |
| 9 | ,909 | 6,493 | 72,777 |  |  |  |  |  |  |
| 10 | ,881 | 6,291 | 79,067 |  |  |  |  |  |  |
| 11 | ,847 | 6,051 | 85,118 |  |  |  |  |  |  |
| 12 | ,778 | 5,558 | 90,677 |  |  |  |  |  |  |
| 13 | ,749 | 5,352 | 96,028 |  |  |  |  |  |  |
| 14 | ,556 | 3,972 | 100,000 |  |  |  |  |  |  |
| Extraction Method: Principal Component Analysis. |



**Figure 13.** Scree plot criterion

**Table 7.** Rotated Component Matrixa

|  |  |
| --- | --- |
|  | Component |
| 1 | 2 | 3 | 4 | 5 |
| Digital communication | .763 | .119 | .076 | .051 | -.048 |
| Digital emotional intelligence | .739 | .102 | -.013 | .075 | -.098 |
| Abstraction | -.082 | .738 | .153 | .015 | .146 |
| Decomposition | .022 | .644 | .068 | -.162 | .130 |
| Patterns and generalization | .376 | .622 | -.137 | -.204 | .072 |
| Algorithms | -.053 | .081 | .593 | .197 | -.349 |
| Evaluation | -.066 | .296 | .567 | -.478 | .037 |
| Logical reasoning | .155 | .047 | .544 | -.015 | .043 |
| Digital security | .100 | .110 | .061 | .576 | .052 |
| Digital safety | .215 | .183 | -.005 | .519 | -.052 |
| Digital literacy | -.092 | .029 | .124 | -.053 | .534 |
| Digital use | .029 | .020 | -.113 | -.069 | .520 |
| Digital rights | .010 | .048 | -.374 | -.149 | .511 |
| Digital identity | -.253 | .109 | .028 | .410 | .482 |
| Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. |
| a. Rotation converged in 9 iterations. |

Figure 14 illustrates the construct of digital intelligence, as it has been derived from the preceding analysis.



**Figure 14.** Proposed categorisation of Digital Intelligence elements

* 1. *Answering RQ2*

In order to correlate the students’ average performance on each of the five groups (Table 8) with their DI score, Pearson’s correlation coefficient was used. This coefficient was used since we had to correlate two quantitative variables. The first one is students’ average performance in each of the five groups, which was calculated as follows: the function “count if” was used to count the correct answers in each test and then the correct answers of all the tests belonging to each group were summed up and divided by the number of the tests in the group. The second one is students’ DI score, which was calculated as follows: the correct answers (one point per correct answer) of each student in all the tests were summed up and divided by fourteen, i.e. the total number of the tests.

As Table 8 indicates, the best performance is viewed in digital security and safety, whereas the worst is concerned with abstraction, decomposition, and patterns & generalization. Notably, the latter is the group of elements that proved to be the one with the highest relation to DI, as indicated in Table 9, which presents the correlations of DI score with students’ average performance in each of the five groups. The lowest performance in the group “abstraction, decomposition, and patterns & generalization” is in line with the correlation result, since the students’ overall performance in all the tests was poor.

**Table 8.** Average performance in the five groups of DI

|  |  |
| --- | --- |
| Digital intelligence groups | Average performance |
| digital emotional intelligence and communication | 283.00 |
| digital security and safety | 416.50 |
| digital rights, identity, use, and literacy | 303.25 |
| logical reasoning, and algorithms | 277.33 |
| abstraction, decomposition, and patterns & generalization | 195.67 |

**Table 9.** Correlations of DI score and students’ average performance on each of the five groups

|  |  |  |
| --- | --- | --- |
| Digital intelligence groups | Pearson Correlation\*\* | Sig. (2-tailed) |
| digital emotional intelligence and communication | .551 | .000 |
| digital security and safety | .472 | .000 |
| digital rights, identity, use, and literacy | .562 | .000 |
| logical reasoning and algorithms | .560 | .000 |
| abstraction, decomposition, and patterns & generalization | .572 | .000 |

\*\* Correlation is significant at the 0.01 level (2-tailed).

1. **Discussion**

Digital intelligence is a construct rarely examined, so far, in literature. Adams (2004) used the term to describe the effects of digital technology on people’s lives and the changes made in communication, lifestyle, economic practices, and the way of thinking, while DQ Institute (2019) defines DI as “a comprehensive set of technical, cognitive, meta-cognitive, and socio-emotional competences that are grounded in universal moral values and that enable individuals to face the challenges and harness the opportunities of digital life and adapt to its demands” (p. 8).

 Our study assists in analysing the construct based on the characteristics that a digitally intelligent individual should have in the emerging digital environment. The study reviews that DI consists of Computational Thinking (CT) and Digital Use & Behaviour (DUB). Both concepts are well studied as separate fields. However, computational thinking does not include digital use and behaviour issues (Wing 2006, 2011), while digital use and behaviour does not comprise elements of thinking (DQ Institute 2019). The two concepts complete each other when combined, eliminating any shortcomings.

The current study explores the latent factors underlying the fourteen elements of DI by using exploratory factor analysis (EFA). The results of the study provide evidence that DI elements can be grouped in five categories, as presented in Section 4.2. This outcome is in line with the descriptive analysis given in Sections 2.3.1 and 2.3.2, since some of the fourteen elements have similar traits. More specifically:

* Logical reasoning, algorithms, and evaluation: logical reasoning describes an attitude where an individual can logically extract the outcome of a process based on facts. In the same way, evaluation is used to describe a process of solving problems based on data assessment, as well as on experience. Algorithms are also used as a notion of predicting the outcome of a series of events, using a step-by-step consistent examination. The common aspect among the three is the estimation of a procedure’s outcome, based on data evaluation.
* Abstraction, decomposition, and patterns & generalisation: abstraction refers to a problem-solving attitude in which it is more effective to detect the less significant information and keep only the critical pieces of information. Moreover, as Bocconi et al. (2016) summarise, abstraction is used in defining patterns, generalizing from instances, and parameterisation (generalisation). Similarly, decomposition suggests breaking down a problem into smaller ones, in a way that leaves out non-essential information. Patterns & generalisation assumes that you can identify a pattern for solving a problem by demanding a reduction of insignificant factors. The common aspect among the three is the focus on solving problems by simplifying them.
* Digital emotional intelligence and digital communication: digital emotional intelligence refers to the ability to recognize and be supportive of someone’s feelings, needs, and concerns online, and express emotions using digital platforms. Digital communication focuses on communication and collaboration by using digital technology. They both have the common aspect of sharing and understanding feelings in the digital world.
* Digital safety and digital security: digital safety describes the ability to understand, mitigate, and manage various cyber risks that relate to personal online behaviours through safe, responsible, and ethical use of technology. Digital security is used for the ability to detect, avoid, and manage different levels of cyber threats to protect personal data, devices, networks, and systems. They both refer to the protection from risks and threats.
* Digital identity, digital use, digital literacy, and digital rights: digital identity focuses on building a “healthy” online and offline identity and demonstrates ethical and considerate behaviour and netiquette when using technology. Digital use is described as the ability to use technology in a balanced way through the rational use of technology. Digital literacy describes the ability to handle media and online information, with critical reasoning, assessing reliability and credibility of online information. Digital rights refer to the ability to handle personal online information with discretion, when using technology as digital citizens. They are all shaped around the digital personality that we should develop in the digital environment, and the need to be digitally familiar.

The results of the current study have significant theoretical and practical implications. On the theoretical side, our results shed some light on the gap identified in the literature review and they unfold in three areas: (i) the study and understanding of the digital intelligence construct, (ii) the analysis of its components, and (iii) the development of a methodological approach for creating a measurement tool. Moreover, grouping the elements of DI into a smaller number of categories could assist in more effective and focused assessment of DI. Using the methodological steps employed for the tests of this study, a revised set of tests could be developed to assess DI in each of the five groups.

On the practical side, implications unfold in three domains: vocational guidance, employee selection and evaluation, and education. We strongly believe that DI is the intelligence of the future since literally all professions embrace information technology to a certain degree. Therefore, assessing DI per group may further assist vocational guidance, since it could provide indications concerning which profession someone should follow. For example, achieving a high score in “digital security and digital safety” indicates a tendency to professions related to cryptography, blockchain, etc. A great score in “digital emotional intelligence and digital communication” reveals someone who may better succeed in professions, such as social media developer, digital marketeer, etc.

Current employee selection and evaluation methods usually seek to assess an employee’s ability in using technology. However, the extensive digitalization of today’s working environment stresses the need for digitally intelligent employees that have deeper understanding of technology. Our study brings out a new approach that should be considered, suggesting that DI groups are apparent for the selection, evaluation, and allocation of human resources. Moreover, as it explores focused intelligence aspects, it can provide an indication of the potential for employee development, which is a crucial aspect of a company.

Finally, the DI construct could assist educational institutes and policy makers to develop new educational models to better prepare students for the emerging digital environment. Until now, the focus was on acquiring digital skills (van Lar, van Deursen, van Dijk, and de Haan 2017) that have been embedded in the national curriculum of many countries (Ananiadou and Claro 2009). However, Calvani, Fini, Ranieri, and Picci (2012) found that adolescents are digitally competent when it comes to technical skills, but not so in higher-order cognitive skills. They concluded that schools should integrate technological abilities with a more articulate cognitive framework related to other significant competences. Our study findings enhance this conclusion by proposing five groups of DI as necessary parts of the cognitive framework.

1. **Conclusion**

The emergence and growth of the ubiquitous digital environment poses great challenges as far as everyday activities are concerned, since people have to adapt to a new environment. Even more, the literature provides indications that it affects the process of thought, altering traditional cognitive tasks, implying that a new way of thinking has started to emerge. This new way of thinking in the digital environment embraces elements of algorithmic thinking, behavioural types, and technology usage attitudes, and could be described under the construct of digital intelligence (DI).

DI, however, is a construct rarely examined in literature. Although the extant literature was thoroughly reviewed, very few references on this construct were found. The two most related concepts to DI are “computational thinking” (CT), as mainly described by Wing (2006, 2008, 2011) and “digital use and behaviour” (DUB), as introduced by DQ Institute (2019). Both concepts examine separate characteristics that digitally intelligent individuals should have. Their combination is the most relevant notion to the DI construct, as presented in this work.

Our study employs an Exploratory Factor Analysis to explore the construct of DI, proposing that it consists of five distinct groups: 1) logical reasoning, algorithms, and evaluation, 2) abstraction, decomposition, and patterns and generalization, 3) digital emotional intelligence and communication, 4) digital safety and security, and 5) digital identity, use, literacy, and rights. This statistical result is in line with the descriptive analysis of the main characteristics of the above elements. Moreover, the group “abstraction, decomposition, and patterns & generalization” was found to be the one with the highest relation to DI, whereas the students did their best in the group of “digital safety and digital security”.

Due to the lack of a satisfactory number of references to DI, there were no data and test results to compare with. In addition, the tests used in the current research are original and therefore the validation process could only be held internally, using a panel of experts. Moreover, even though the sample size was sufficient, the research was only focused on a Greek Regional Unit and therefore the findings should be generalised with care if extrapolated to other settings. Another limitation is that, when we develop tests to access “digital use & behaviour”, we should consider that in some cases there is not a unique correct answer because behavioural aspects might be ambiguous. Future research could be concentrated on implementing a Confirmatory Factor Analysis (CFA) to confirm the structure of DI, as derived from our analysis. It would also be interesting to conduct similar DI tests by targeting other groups of people.

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No potential conflict of interest was reported by the authors.

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1. Programme for International Student Assessment [↑](#footnote-ref-1)
2. Organization for Economic Co-operation and Development [↑](#footnote-ref-2)