








# Digital maturity of young people – unfolding dependencies between core dimensions and national context as external factor by using a machine-learning approach

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## ABSTRACT

In recent years, the interest in determining what constitutes a beneficial use of information and communication technologies (ICTs) has increased, especially with a focus on young people and their digital maturity. To design effective interventions for promoting beneficial digital engagement among young people, it is crucial to understand the interdependency between the core capabilities and digital maturity. Furthermore, how external factors, such as national context, might influence the establishment of an overall index score. Therefore, this paper sets out to validate the digital maturity index and determine the most important dimensions as well as explore if the measurement framework can be considered independent from national context. To do this, we collected data across multiple rounds from 2021 to 2022 (N = 2804) in five European countries (AT, DE, GRE, SLO, DK) and explored it using a novel machine learning approach. We conclude that digital maturity dimensions need further in-depth investigation as some dimensions are subject to more volatility with regard to the context and content of the study. Furthermore, national context plays a crucial role in not only young people's use of ICTs but also in their development of digital maturity.

## 1. Introduction

Digital information and communication technologies (ICTs) are rapidly evolving and affects more and more areas of our lives. Accessibility and usage of ICTs are mainly driven by the use of mobile devices, leading to around 4.25bn exclusively mobile internet users worldwide (Statista, 2024). These digital developments, integrated into most of our everyday life activities, become even more significant with regard to children and adolescents (Vissenberg et al., 2022). An increasing number of young people regularly interact with mobile ICTs and grow up as „digital natives“ (Kesharwani, 2020; Livingstone et al., 2018; Mascheroni & Olafsson, 2016).

An important aspect when it comes to young people's use of ICTs is that it comes with certain opportunities and benefits but also challenges (Ólafsson et al., 2013). On the one hand, ICTs are seen as facilitator where the 'digital generation' can get support for educational learning,

engage in civic activities, be creative and express themselves, as well as create their own identity and connect with others (Livingstone et al., 2018). On the other hand, using ICTs can also make young people more prone to digital risks (Livingstone et al., 2021). This is where the use of ICTs is seen as an inhibitor, which can impact their overall health and well-being (Vissenberg et al., 2022). For instance, young people, who struggle to control their use of social networking websites or gaming, may end up spending excessive amounts of time on their devices, neglecting other important activities. This can lead to accompanying risks, such as the various forms of addiction (Haug et al., 2015; Tsitsika et al., 2014). Being able to pursue online opportunities and avoid digital risks are not necessarily mutually exclusive. Young people's increased engagement in digital activities and enjoyment of online opportunities has been found to heighten their exposure to digital risks (Helsper & Smahel, 2020; Livingstone et al., 2017). This has led to growing attention on digital capabilities and their role in helping young people to take

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advantage of the benefits while concurrently being aware of the digital challenges (Laaber et al., 2023; Livingstone et al., 2021; Livingstone & Helsper, 2010).

The literature on young people’s digital capabilities has predominantly focused on dimensions such as digital literacy and lacks a more interdisciplinary perspective (Livingstone et al., 2018; Reid Chassiakos et al., 2016). While digital literacy is perceived as important for enabling young people to engage safely and effectively with ICTs in the digital environment (Livingstone et al., 2018), it focus primarily on basic technical capabilities to use mobile devices (Laaber et al., 2023). Recent research has highlighted the need for a more comprehensive understanding of young people’s use of mobile devices, which considers the broader social and cultural contexts of their digital engagement (Livingstone et al., 2021). To address this need, the concept of digital maturity has been proposed as a more holistic approach to understanding young people’s ICT-related activities (Laaber et al., 2023).

Digital maturity encompasses a range of capabilities beyond technical skills and is defined “as the capabilities and attitudes which enable individuals to use digital technologies in ways which support individual development (growth) and integration into society (adjustment)” (Laaber et al., 2023, p. 2). Gaining digital maturity supports young people to navigate in the complex digital environment and make informed choices about their digital engagement (Laaber et al., 2024). Research has already shown the usefulness of digital maturity in explaining young people’s problematic mobile device use and aspects of wellbeing (i.e., life satisfaction (Laaber et al., 2024)), being associated with adolescents’ socio-economic status (Koch et al., 2024) and personality traits (e.g., Big5, self-regulation (Koch et al., 2024; Laaber et al., 2023);).

However, although the conceptualization of digital maturity to explain beneficial and maladaptive ICT behavior of young people seems to be promising (Laaber et al., 2023, 2024), further research on the different capabilities composing digital maturity and thus, the establishment of an overall index score of digital maturity is crucial. As the composition of digital maturity and therefore its overall index score is aggregated by underlying dimensions (Laaber et al., 2023), it needs more clarity on how each of them is contributing (e.g., through relative importance) to the establishment of digital maturity in general and in terms of stability and volatility.

Furthermore, young people’s ICT use and thus their level of digital maturity can be influenced by external factors, such as social norms (Mano, 2021) or social patterns of parental mediation (Kirwil, 2009; Koch et al., 2024). Here, especially the national context (e.g., the national level of digital competence (Hietajärvi et al., 2023; Juhász et al., 2022)) is a crucial external factor for facilitating young people’s online experience (Lobe et al., 2011). Thus, we need to identify whether the capabilities of the digital maturity are prone to differences in the national context (e.g., similar or different cross-national contribution to a digital maturity score).

Against this background, we will introduce a new method using fuzzy metrics and random forest models (Beaulac & Rosenthal, 2019; Majid & Ahmad, 2022) to further validate its underlying measurement framework and investigate dependencies between national context as an external factor of digital maturity. More specifically, our aim is to.

1. Unfold the overall index score for digital maturity by using machine learning models to determine the relative importance of capabilities and assess their level of stability or volatility (RP1 & RP2),
2. Investigate if digital maturity is stable with regard to different national contexts or shows a higher proneness to be dependent on national context (RP3).

By pursuing these goals, this paper advances our understanding of digital maturity and the dependencies between digital capabilities in the context of young people. Practitioners and policymakers can use this enhanced understanding and knowledge to design campaigns and interventions to foster the development and establishment of young

people’s digital maturity and promote the use of digital devices in a healthy direction.

The remaining sections of this paper are structured as follows. The theoretical framework provides an overview of the literature on young people’s use of ICTs, the conceptualization of digital maturity and formulated research propositions. The methodology offers argumentation for the chosen machine-learning approach that is used to unfold the dependencies between capabilities and the overall index score for digital maturity as well as influence of national context, followed by a discussion, limitations, and future research suggestions.

## 2. Theoretical background and research proposition

### 2.1. Digital maturity in the context of young people

Originally, digital maturity emerged as a useful framework for assessing organizations’ progress toward digital transformation (Thordsen et al., 2020). Over the past years, several frameworks for measuring digital maturity have been introduced (Thordsen & Bick, 2023). These frameworks contribute to understanding what capabilities are needed to become digitalized and evaluates organizations’ digitalization level, readiness to digitalization, and digitalization strategy (Aslanova & Kulichkina, 2020; Williams et al., 2019). While these frameworks serve as relevant to expand our knowledge of digital maturity in a business context, there is still a need for investigating what capabilities are needed in young people. Unlike in an organizational context, where the drivers of digital transformations are related to different capabilities, the use of technologies in the context of young people is related to capabilities of personal development. Young people need to obtain certain digital capabilities when using their digital technologies. Considering these differences, the notion of digital maturity, along with relevant capabilities, was recently extended and modified for young people (Laaber et al., 2023).

Derived from the concept of psychosocial maturity (Greenberger et al., 1975), digital maturity in the context of young people include capabilities that are tailored to young people’s beneficial technology use (Laaber et al., 2023). Overall, it encompasses three fundamental capacities - the capacity to i) use digital technologies in an autonomous and self-determined way, ii) master increasing digital challenges and solve problem, and iii) interact adequately with others and to contribute to society – and underlying capabilities (dimensions of digital maturity) that young people should develop to use ICTs in a self-determined and socially responsible way (Hofmans et al., 2024; Laaber et al., 2023). An overview of the three fundamental capacities and associated capabilities are presented in Table 1. First, the *capacity to use digital technologies in an autonomous and self-determined way* is associated with dimensions of young people’s liberty and flexibility to decide on their own when, how

**Table 1**  
Capacities and capabilities of digital maturity.

Capacities	Capabilities (Dimensions)
The capacity to use digital technologies in an autonomous and self-determined way	Autonomous Choice to Use Mobile Devices Autonomy Within Digital Contexts
The capacity to master increasing digital challenges and solve problems	Digital Literacy Digital Risk Awareness Individual Growth in Digital Contexts Support-Seeking regarding Digital Problems
The capacity to interact adequately with others and to contribute to society	Regulation of Negative Emotions Within Digital Contexts Regulation of Impulses Within Digital Contexts Respect Towards Others Digital Citizenship

and why they want to use mobile devices and digital activities (*Dimension 1 – Autonomous Choice to Use Mobile Devices*) and consume and interact with different forms of digital context (*Dimension 2 – Autonomy Within Digital Contexts*) (Laaber et al., 2023, 2024). Second, the *capacity to master increasing digital challenges and solve problems* is mainly associated with young people's general digital capabilities to navigate within digital environments (*Dimension 3 – Digital Literacy*) and to be able to reflect on potential negative effects affecting their well-being (*Dimension 4 – Digital Risk Awareness*). Nevertheless, to develop in digital maturity, young people need to allow themselves to learn and establish those capabilities. Thus, they should be able to facilitate knowledge and enable themselves to develop (*Dimension 5 – Individual Growth in Digital Contexts*), but also to have the capabilities to know, when they should reach out to others for support (*Dimension 6 – Support-Seeking regarding Digital Problems*) (Laaber et al., 2023, 2024). Third, the *capacity to interact adequately with others and to contribute to society* is an important component of digital maturity as it goes beyond the individual development regarding the first two capacities by focusing on beneficial aspects of peer-to-peer interaction, respectful online behavior and contributions to society (Jones & Mitchell, 2016). A main component of adequate digital communication refers to young people's capabilities to regulate negative emotions (*Dimension 7 – Regulation of Negative Emotions Within Digital Contexts*) and impulses (e.g., to express anger or frustration on social media) in digital environments (*Dimension 8 – Regulation of Impulses Within Digital Contexts*). Furthermore, as critical aspects of maladaptive online behavior (e.g., cyberbullying, neglect of societal issues such as climate change) is increasing over the past years (Rousseau, 2024; Williams et al., 2015; Zhu et al., 2021), developing digital maturity is evident in young people's capability of a reflective and respectful digital behavior (*Dimension 9 – Respect Towards Others*) and their willingness to engage in societal-relevant issues (*Dimension 10 – Digital Citizenship*) (Laaber et al., 2023, 2024).

As digital maturity is a formative higher-order construct formed by its underlying capacities and capabilities, the identification and extraction of important digital maturity dimensions and a potential overall index score for digital maturity offers benefits for i) better interpretability of digital maturity developments, ii) setting of benchmarks, and iii) segmentation purposes. However, we still lack a general understanding of how each of the capabilities within the three areas of young people's digital capacities contributes to digital maturity. Research already indicates that – while the concept of digital maturity is relatively robust – some capabilities (e.g., support seeking, emotion regulation) might have different relative importances in building an overall digital maturity score (Hofmans et al., 2024). Topics such as establishing basic digital capabilities, creating a higher awareness of digital risks (Rodríguez-de-Dios et al., 2018), or the need for digital flourishing in online environments (e.g., respectful conversations; Law et al. (2020); Rosic et al. (2022)) have gained attention as crucial drivers of young people's development (Subrahmanyam et al., 2001). Thus, indicating a higher expected weight on young people's establishment of digital maturity. On the other hand, the search for external support and the establishment of societal engagement in digital environments often needs a higher form of general maturity with regard to learning, knowledge sharing and goal orientation (Crone & Dahl, 2012). Thus, indicating a lower expected weight on young people's establishment of digital maturity. Therefore, we propose.

**RP1:** Capabilities for digital maturity will contribute differently in their relative importance to the establishment of an overall digital maturity index score. Capabilities strongly associated with personality development (e.g., digital risk awareness, individual growth) will have a higher relative importance than capabilities strongly associated with peer-to-peer interaction and societal contribution (e.g., digital citizenship, support seeking).

Furthermore, in addition to the differences in the relative importance of young people's capabilities, we also expect that the underlying dimensions differ in their level of stability and volatility. Young people's behavior with digital devices has been found to vary, and research indicates differences in young people's digital engagement (Livingstone & Helsper, 2007). Hence, the influence of the capabilities on young people's digital maturity might be impacted by the frequency with which they perform typical online behaviors when using their digital devices or how they use the Internet and mobile devices (Laaber et al., 2023). Therefore, we also propose that some dimensions (e.g., support seeking, emotion regulation) might show more volatility in their contribution to an overall index score for digital maturity score whereas other capabilities (e.g., digital literacy) might be more stable in their effects across the different frequency levels.

**RP2:** Capabilities for digital maturity will contribute differently in their volatility to the establishment of an overall digital maturity index score. Capabilities more strongly associated with young people's digital engagement (e.g., digital risk awareness, individual growth) will have higher volatility than capabilities more strongly associated with establishing a knowledge base of ICT use (e.g., digital literacy).

## 2.2. Impact of national context on digital maturity capacities and capabilities

The development of behavioral patterns and decision-making processes, and their associated outcomes (e.g., people's well-being, knowledge, and capability development) as well as differences between individuals, are often driven by the influence of external factors such as demographics (e.g., socio-economic status (SES)), social influences (e.g., peer and family influence) or the national context (e.g., economic and social norms) (Erumban & de Jong, 2006; Lobe et al., 2011; Van Everdingen, 2003). Especially national context indicates differences in socio-economic stratification, regulatory framework, technological infrastructure, education system, and cultural values (Ayllón et al., 2020; Lobe et al., 2011; Smahel et al., 2020). Recent research provided evidence for a strong moderating effect of national context (e.g., differences in national economics and culture) on relationships between personality dimensions and life satisfaction (Bond et al., 2020) and between work/family conflict and social support (French et al., 2018). Furthermore, existing research already offered insights into the explanatory power of national context as a potential moderator of young people's online behavior and experiences with regard to differences in young people's digital inequalities and mental health relationships (Gracia et al., 2023) or their perception and evaluation of online risk and safety (Lobe et al., 2011).

As digital maturity - determined by young people's digital experiences - is strongly content- and context-driven (Hofmans et al., 2024; Laaber et al., 2023), research indicates an influence of external factors such as demographic (i.e., socio-economic status) and social factors (i.e., parental mediation) on the establishment of digital maturity (Koch et al., 2024). However, knowledge about the influence of national context on the composition of digital maturity and thus, the importance of young people's digital maturity capacities and capabilities within and between national contexts is scarce. For instance, with regard to the first capacity - the *capacity to use digital technologies in an autonomous and self-determined way* - some countries (e.g., Denmark) focus on developing initiatives that promote children's rights and freedom in order to strengthen their autonomous choices to use digital devices (Lobe et al., 2011). On the other hand, some countries (e.g., Germany) have stronger restrictive mediation of young people's internet use (e.g., through parental norms) (Livingstone et al., 2011), which in consequence limits young people's autonomy within digital contexts. With regard to the second capacity - *capacity to master increasing digital challenges and solve problem* - the development of the technological infrastructure worldwide

and internet connection rates that reach very high levels allows young people to access the internet more frequently (van Deursen & van Dijk, 2019), which, in general, enable them to pursue individual growth and learn new things through their digital devices. On the other hand, there are national differences regarding the level of digital competitiveness (Statista, 2023), the education of basic digital skills (Eurostat, 2021), educational systems or the degree of digital inequalities (Gracia et al., 2023), which might influence the establishment of capabilities to master increasing digital challenges (e.g., digital literacy, digital risk awareness) and solve problems within digital environments. With regard to the third capacity - *the capacity to interact adequately with others and to contribute to society* - regulatory frameworks on how people should behave and regulate themselves within digital environments but also the facilitation of societal engagement is often similar and thus context-independent (e.g., digital rights and principles; European Commission (2024)). Thus, we propose national context as an important moderating component for national differences in establishing young people's digital maturity.

**RP3:** The overall index score for digital maturity is dependent on national context and some countries will show more importance in predicting young people's digital maturity in comparison with other countries.

### 3. Method and results

#### 3.1. Participants, questionnaire and country Selection

The study used self-reported data from a three-round cross-country survey conducted from 2021 to 2022 (N = 2804) for the DIGYMATEX Horizon Europe project. All online questionnaires were administrated in Qualtrics and distributed through professional market agencies in five countries (AT, DE, GRE, SLO, DK). The first round included Austria and Germany, whereas the second and third round included Greece, Slovakia, and Denmark.

In all questionnaires, the Digital Maturity Inventory (DIMI, 36 items) was used to cover the three capacities and associated ten capabilities (dimensions) of Digital Maturity (Laaber et al., 2023). All the items, shown in Appendix A, were answered on a 5-point Likert scale. Items were priorly tested for age appropriateness and translated into the respective language (Laaber et al., 2023, translation protocols are available at <https://digymatex.eu/digital-maturity-inventory-dimi/> and <https://soko-psy.univie.ac.at/research/projects-and-research-interests/individuals-in-a-digital-world/digymatex-understanding-childrens-digital-maturity/>). Cronbach's alpha for each of the measured capabilities across countries ranged between 0.72 and 0.91, demonstrating satisfactory internal consistency (See Appendix B).

At the beginning of the online questionnaire, the participants and one of their parents provided written informed consent for the study as the participants were under the age of 18. The informed consent form included information about the purpose and background of the study. Participants were informed about the procedure, what was required of them, their rights, potential risks, and how the data would be processed. At the end of the online survey, information about participant anonymity and the confidential handling of data was provided along with contact details before the participants had to provide a final written consent to submit their responses. Ethical assessments were conducted and approved by responsible Research Ethics Committees. In Table 2, the sample characteristics are presented.<sup>1</sup>

The chosen countries were selected based on potential differences and cross-country variation with regard to levels of (i) socio-economic stratification, (ii) regulatory frameworks, (iii) technological

infrastructure, (iv) education systems and (v) cultural values. Socio-economic stratifications were operationalized as digital inequalities and differences in young people's internet access and use of digital technologies. Young people in Denmark, Germany, and Austria report higher access to and higher use of the internet in comparison to young people in countries such as Greece and Slovakia (European Commission, 2019; Notten et al., 2009). The regulatory framework was operationalized using the country's level of press freedom (i.e., a freer media opens up more widespread usage of the internet and freedom of expression - according to Lobe et al. (2011), Denmark has more press freedom than, for instance, Greece). Moreover, parents from Austria report higher awareness of their children's online activities and parental mediation than parents in, e.g., Slovakia (European Commission, 2019). Technological infrastructure was operationalized based on the differences in digital competitiveness and broadband penetration (Stankovic et al., 2021). For instance, Germany has higher broadband penetration compared to Greece (Lobe et al., 2011). In terms of the country's education system, there are differences in access to equipment (i.e., computers and laptops) and the number of young people who are enrolled in highly digitally equipped and connected schools. Denmark shows, for example, higher rates than Greece (European Commission, 2019). Lastly, cultural values and norms were operationalized using the country's adoption levels of digital technologies based on insights from Erumban and de Jong (2006) where the ICT adoption across countries was found to be associated with a country's cultural factors.

#### 3.2. Methodology

To study how the overall index score for digital maturity is impacted by the core capabilities and to unfold the dependencies between them, we employed an unsupervised fuzzy machine learning approach. Unsupervised machine learning allows for exploring the underlying structure of the data. Given that no external variable was available for discovering the dependencies between dimensions and the overall index score for digital maturity, an unsupervised approach that measures the proximity to digital maturity was more suitable. Thus, for the construction of the overall index score for digital maturity, we utilized the procedure from Jiménez-Fernández et al. (2022). This included the creation of fuzzy metric spaces for each of the ten capabilities of digital maturity. To accomplish this, the data collected for each of the capabilities was normalized to a value between 0 and 1. After normalizing the data, we calculated the distance to a fixed reference point. The fixed reference point was the highest obtainable score (i.e., the normalized highest obtainable value on the 5-point Likert scale). Following this, the measured distances were combined into an overall index score by using a product triangular norm. In this manner, we created fuzzy metric spaces and accommodated the complexity of combining several dimensions into a single and overall predictable index score for digital maturity. An overview of the pseudocode used for this procedure is provided in Appendix D.

For our analysis, several random forest models were estimated based on the ten capabilities to predict the overall index score for digital maturity. To interpret the estimated random forest models, we applied two standardized procedures - the permutation-based variable importance method (PVI) and the partial dependence plots (PDPs). The details about our method are presented in Appendix C. These two procedures allowed us to derive the relative importance of the capabilities and get a comprehensive view on how they contribute to the overall index score. We utilized the model-agnostic approach that derives the relative importance ranking based on input dimensions by estimating the increase in prediction errors before and after changes were introduced (Greenwell & Boehmke, 2020; Scholbeck et al., 2020). The greater the difference, the more important the dimension. To quantify the uncertainty in the relative importance scores for each of the dimensions, standard errors were obtained based on 50 permutation-based iterations. The most important (core) capabilities were derived by adding up

<sup>1</sup> A version of the raw data may be obtained upon request by contacting the corresponding author.

**Table 2**  
Sample characteristics.

	Austria (N = 1254)	Germany (N = 1010)	Denmark (N = 142)	Greece (N = 260)	Slovakia (N = 138)	Overall (N = 2804)
Age						
Mean (SD)	14.7 (1.77)	14.8 (1.66)	15.0 (1.65)	15.1 (2.04)	14.8 (1.91)	14.8 (1.77)
Median (Min, Max)	15.0 [12, 18]	15.0 [12, 18]	15.0 [12, 18]	15 [12, 18]	15.0 [12, 18]	15 [12, 18]
Gender						
Female	602 (48.0 %)	507 (50.2 %)	70 (49.3 %)	116 (44.6 %)	75 (54.3 %)	1370 (48.9 %)
Male	646 (51.5 %)	500 (49.5 %)	72 (50.7 %)	141 (54.2 %)	63 (45.7 %)	1422 (50.7 %)
Other	6 (0.5 %)	3 (0 %)	0 (0 %)	3 (1.2 %)	0 (0 %)	12 (0.4 %)

the individual importance scores to obtain a total score of importance and dividing it by the number of capabilities. We considered a capability as more important if it had close to or above 10 % of the total importance. This corresponds to an equal importance for the ten dimensions to predict the overall index score. In this way, we distinguish core capabilities with higher contribution from capabilities with lower contribution to predict the overall index score for digital maturity. PDPs visualize the quantified relationships between the overall index score and the capabilities, marginalized across different input values (Friedman, 2001). The coefficient of variation (CV) was used as a measure for volatility. CV was calculated as the ratio of the standard deviation to the mean, expressed as a percentage. A CV-score of 25 % was chosen as the threshold to distinguish between volatile (CV > 25 %) and stable (CV < 25 %) dimensions.

3.3. Results

First, to predict the overall index score for digital maturity, several random forest models were estimated to capture the effects of the dimensions. The R-squared of the final selected model without country as a predictor was 0.68. Adding country as a potential important predictor

led to an R-squared of 0.84, an improvement of 16 % over the model without country as a predictor. Root Mean Squared Error (RMSE) was 0.0010 and Mean Absolute Error (MAE) was 0.00016.

3.3.1. RP1 - capabilities for digital maturity contribute differently in their importance to the establishment of an overall digital maturity index score

With regard to RP1 - capabilities for digital maturity will contribute differently in their importance to the establishment of an overall digital maturity index score - we obtained their PVI. To assess the level of importance from the core dimensions, a 10 % boundary was identified, corresponding to an equal level of importance for each of the ten dimensions. See Fig. 1 for the permutation-based variable importance scores including standard deviations for all the dimensions.

Overall, each of the ten dimensions shows a positive importance. However, their predictive performance of establishing the overall index score (RP1) for digital maturity varies. The most important dimensions (i.e., importance score >10 %) to predict the overall index score are Digital Risk Awareness (0.115/0.009), followed by the dimensions Respect towards Others in Digital Contexts (0.081/0.006), Support Seeking Regarding Digital Problems (0.069/0.004), and Digital Literacy (0.055/0.006). In addition to digital risks, the ability to show respect

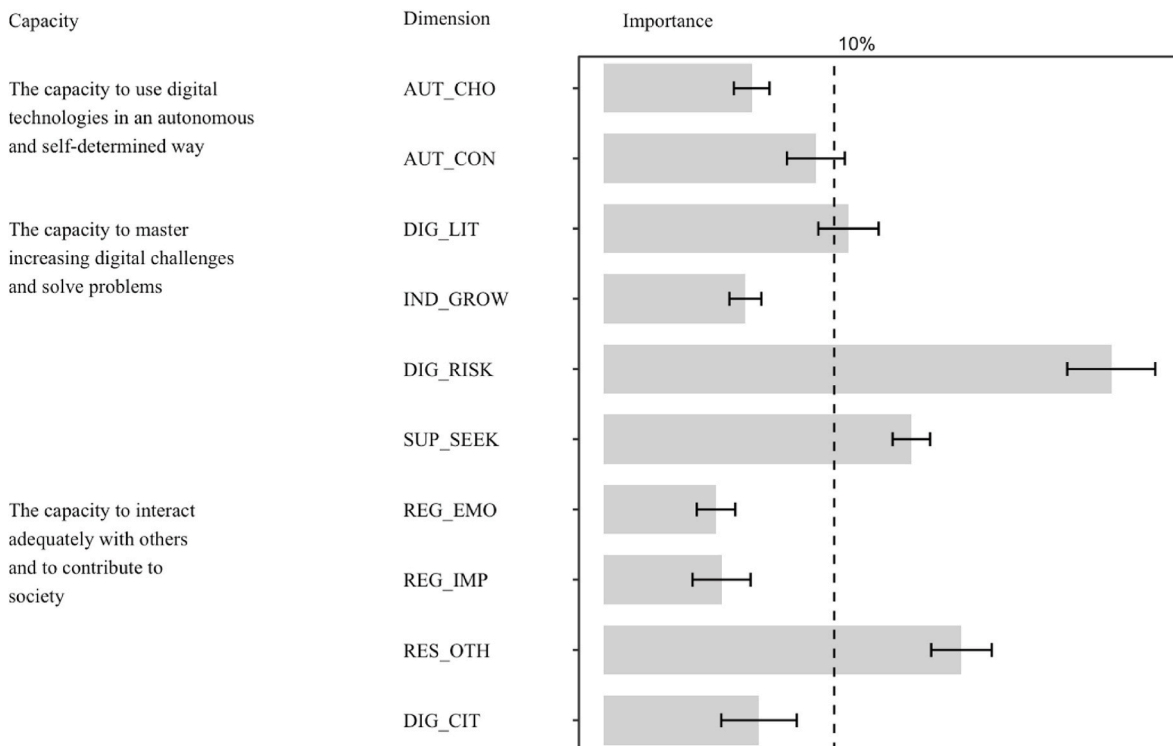


Fig. 1. Permutation feature importance with standard deviations

Note: AUT\_CHO = Autonomous Choice to Use Mobile Devices; AUT\_CON= Autonomy within Digital Contexts; DIG\_LIT = Digital Literacy; IND\_GROW = Individual Growth in Digital Contexts; DIG\_RISK = Digital Risk Awareness; SUP\_SEEK = Support-seeking Regarding Digital Problems; REG\_EMO = Regulation of Negative Emotions in Digital Contexts; REG\_IMP = Regulation of Impulses in Digital Contexts; RES\_OTH = Respect towards Others in Digital Contexts; DIG\_CIT = Digital Citizenship.

towards others, seek support, and having the technical capabilities are important dimensions to predict young people’s overall index scores for digital maturity. With regard to other dimensions, Autonomy within Digital Contexts (0.048/0.006), Digital Citizenship (0.035/0.008), Autonomous Choice to Use Mobile Devices (0.033/0.004), Individual Growth in Digital Contexts (0.032/0.003), Regulation of Impulses in Digital Contexts (0.026/0.006), and Regulation of Negative Emotions in Digital Contexts (0.025/0.004) are the least important dimensions (i.e., importance score <10 %) in predicting the overall index score for digital maturity. These dimensions are useful as predictors, but to a less degree than the most important dimensions.

3.3.2. RP2 - capabilities for digital maturity contribute differently in their volatility to the establishment of an overall digital maturity index score

With regard to RP2 - capabilities for digital maturity will contribute differently in their volatility to the establishment of an overall digital maturity index score - The PVI for each of the dimensions do not indicate how the change of the input value for a particular dimension is associated with a positive or negative increase in the overall index score. Thus, to understand the marginal effects and how each of the dimensions change over a range of input values in relation to the overall index score, the partial dependence plots (PDP) are obtained for each of the dimensions. To assess the variability in the PDPs derived for each of the dimensions, we utilized the coefficient of variation (CV). The CV is a standardized measure of dispersion, which is calculated as the ratio of the standard deviation to the mean, expressed as a percentage (Shechtman, 2013). This metric provides us with an assessment of the PDPs, useful for comparing and quantifying the degree of variation/stability within each of the dimensions and compare across the dimensions. A CV-score of 25 % were chosen as the threshold to distinguish between volatile (CV > 25 %) and stable (CV < 25 %) dimensions. Thus, based on partial dependence plots, we observe that all of the dimensions contribute positively to the overall composite index score as the input value increases. Higher levels of a particular dimension predict a higher overall index score.

However, we also observe that some of the dimensions show a more nonlinearity of relationship with the predicted overall index score. Dimensions, which are observed as having a higher volatility (i.e., a CV-score more than 25 %), are Support-seeking Regarding Digital Problems (CV = 80.1), Digital Risk Awareness (CV = 77.1), Autonomy in Digital Contexts (CV = 65.5), Individual Growth in Digital Contexts (CV = 63.8), and Respect Towards Others in Digital Contexts (CV = 60.9). For Support-seeking Regarding Digital Problems, the PDPs show a positive relation with the digital maturity index score. In comparison with the volatile dimensions, the dimensions Autonomous Choice in Digital Contexts (CV = 24.8), Digital Literacy (CV = 24.4), Regulation of Negative Emotions in Digital Contexts (CV = 20.2), Regulation of Impulses in Digital Contexts (CV = 17.9), and Digital Citizenship (CV = 14.4) are observed as being more stable in their marginal effects (i.e., a CV-score less than 25 %). For Autonomous Choice in Digital Contexts, the PDPs show that a higher score on this dimension positively contributes to an increased digital maturity index score with a small rate of change. The partial dependence plots for all dimensions are shown in Fig. 2.

3.3.3. RP3 - the overall index score for digital maturity is dependent on national context

With regard to RP3 - the overall index score for digital maturity is dependent on national context - similarities and differences in the predictive performance on the overall index score for digital maturity between countries can be observed as well. First, the model including country as a predictor performed better than the model without country as a predictor. Accuracy metrics for the model including country as a predictor were RMSE = 0.00091, R-squared = 0.90, and MAE = 0.00015. For the model without country as a predictor, the accuracy metrics were RMSE = 0.00081, R-squared = 0.66, and MAE = 0.00016. Secondly, the presence of a country effect is observed. Summing each level and looking at the overall contribution of countries as a single predictor reveal that there is an increase in predictive power. Overall, the permuted-based variable importance shows across country levels

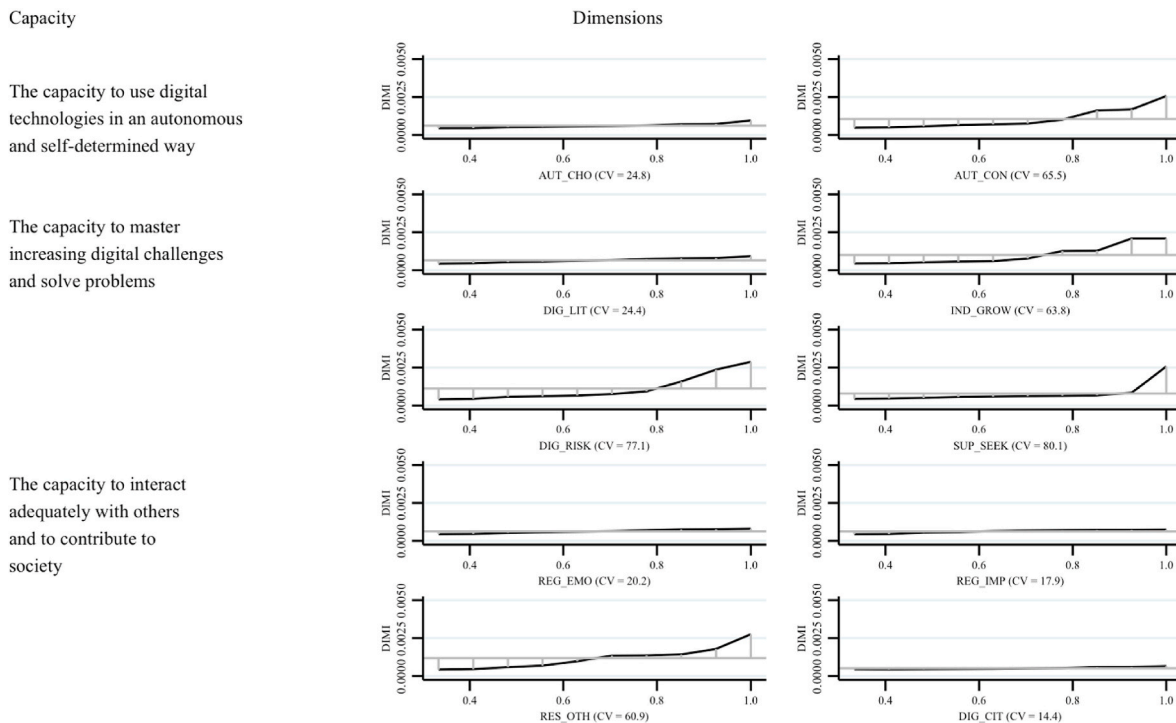


Fig. 2. Partial dependence plots (PDPs)

Note: AUT\_CHO = autonomous choice to use mobile devices; AUT\_CON= autonomy within digital contexts; DIG\_LIT = digital literacy; IND\_GROW = individual growth in digital contexts; DIG\_RISK = digital risk awareness; SUP\_SEEK = support-seeking regarding digital problems; REG\_EMO = regulation of negative emotions in digital contexts; REG\_IMP = regulation of impulses in digital contexts; RES\_OTH = respect towards others in digital contexts; DIG\_CIT = digital citizenship.

that some of the countries carries the effect (i.e., Germany, Austria, and Greece) whereas Denmark and Slovakia do not contribute to predicting the overall index score beyond the individual dimensions. See Fig. 3 for variable importance plots with regard to country-dependent permutation-based variable importance scores. This indicates that the prediction of the overall index score depends on the specific country. Some countries contribute and are important predictors whereas other countries do not contribute to the predictive performance.

#### 4. Discussion

Lately, young people's beneficial use of ICTs has gained attention. However, there is a lack of research on how different capabilities when using ICTs impacts young people's digital maturity. Based on previous work on digital maturity, we proposed three research propositions. First, we assumed that the underlying capabilities (dimensions) of digital maturity contribute differently in their relative importance to the establishment of an overall digital maturity index score (RP1). Secondly, we proposed that some of the digital maturity capabilities (e.g., mastering digital challenges, autonomy in digital environments) are subject to more volatility, whereas other capabilities might show more stability across the range of input values (RP2). Third, the presence of a country effect was suggested (RP3).

##### 4.1. Dependencies between core DM-dimensions and their relative importance

Overall, the relationships between the capabilities and the overall index score show an influence of the former on the latter. This implies that the underlying measurement framework for digital maturity works as intended (Laaber et al., 2023). However, despite the influence on digital maturity, some of the capabilities can be seen as stronger predictors of the overall index score than others. We found that young people's capability to seek support among others is of greater importance. These results are in line with the study by Hofmans et al. (2024), which point out that some dimensions (e.g., support seeking) might have different importances in building an overall digital maturity score. Support-seeking is an important element in the development of autonomy and competence. When young people ask for help from others during uncertain situations, they engage in a validation process that helps them reduce uncertainty by creating a shared view on a situation

(Echterhoff & Higgins, 2017). However, seeking validation not only reduces uncertainty in assessing the specific situation but also facilitates vicarious learning (Bandura, 1989): Young people can learn from the experiences of others. Interestingly, recent theories propose that this kind of learning is effective even in situations when there is no knowledge difference through the described belief sharing and belief updating (Park & Puranam, 2024). In a digital context, belief updating is particularly relevant for adolescents because adolescents often have a more negative view of themselves and confirm this belief in an interpretation of the situation (Ferguson et al., 2024). Consultation with trusted others with different prior beliefs about the adolescent can mitigate these cognitive biases and provide alternative perspectives. Moreover, when young people actively seek support from parents or other trusted persons, this behavior can foster secure attachment relationships that enhance autonomy by creating a supportive framework for independent digital exploration (Koch et al., 2024).

For future modifications of the importance of especially Support-seeking Regarding Digital Problems, it can be necessary to look into how age influences, in particular, this relative importance score. Along with Support Seeking Regarding Digital Problems, Digital Literacy and Digital Risk Awareness can also be seen as important antecedents when predicting young people's digital maturity overall index score. These are constructs that have gained a lot of attention from researchers in recent years. Their relevance in determining young people's use of ICT has already been well-demonstrated in research (Atkinson & Newton, 2010; Haddon & Livingstone, 2017; Vissenberg et al., 2022). When combined with support seeking, they might help to identify fraudulent activities, cyberbullying, or other digital threats. Support seeking, digital literacy, and risk awareness can be seen as a synergistic triad of digital maturity that reflects autonomy and competence as the theoretical basis of digital maturity. When people have a heightened awareness of digital risks, they are better able to recognize when their skills are insufficient to safely and effectively overcome a particular digital challenge. Existing digital literacy helps with this assessment. People with stronger digital literacy are better able to recognize the limits of their own abilities and decide when to seek help from others. The behavior when seeking support then serves as an active intervention mechanism that not only reduces immediate risks but also creates opportunities for learning and developing skills. Hence, all three aspects reinforce the core theoretical premise of digital maturity: developing these skills enables young people to use digital technologies in ways that promote self-determination

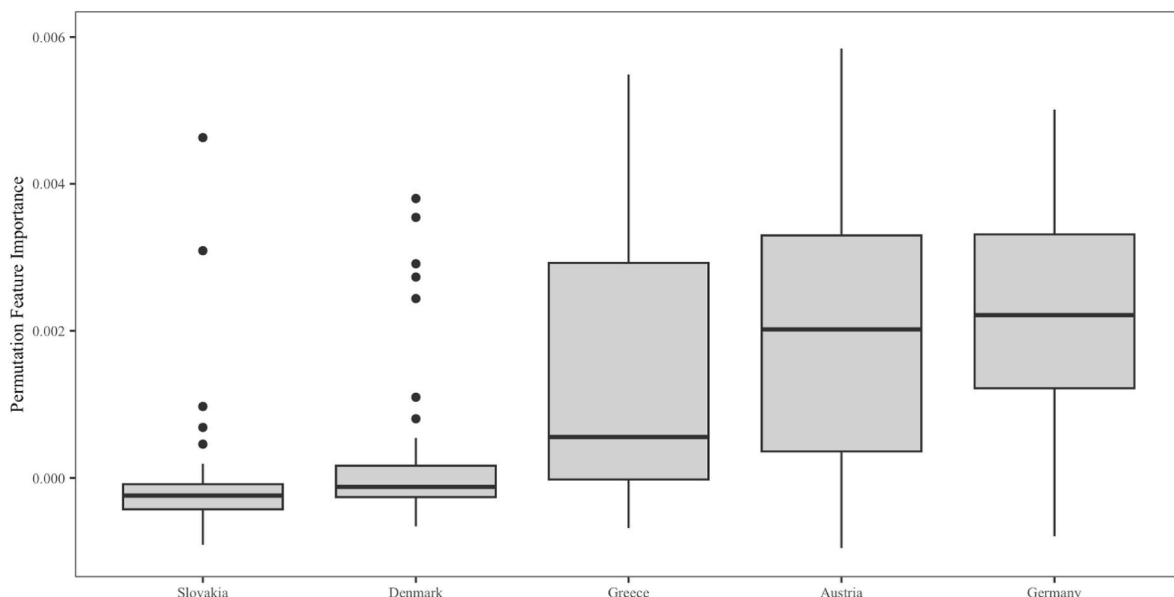


Fig. 3. Permutation feature importance of Country-dependent impact on the overall index score.

(Laaber et al., 2023).

With this new division of the core dimensions, our analysis shows that certain dimensions are more central to the concept of digital maturity than others. This means that the loadings for each of the dimensions in the current version of DIMI can be reconsidered, and more weight could be attributed to the identified important core aspects. Currently, small differences already exist in dimension weights derived from a normative point of view (Laaber et al., 2023). For instance, Respect towards Others in Digital Contexts was rated as one of the more important dimensions to achieve digital maturity. However, this does not mean that the less central dimensions are unimportant. They may be very important in certain situations and will likely require specific interventions when an improvement is desired.

#### 4.2. Dependencies between core DM-dimensions and their stability/volatility

Moreover, it was found that the volatility of the dimensions is not the same, and higher levels on individual dimensions denote a higher overall index score for digital maturity. Marginal increasing effects were observed at lower levels, but the increasing marginal effects and the magnitude of this positive impact increased more significantly at higher levels. This indicates that the effect of some dimensions is more pronounced after certain levels are obtained. Beyond these levels, the higher score on these capabilities, the better the overall index score. This extends our understanding of how the operationalization of digital maturity works and points to the fact that certain levels on the digital maturity capabilities should be aimed at as the effect is triggered at a given frequency level. For dimensions such as *digital literacy*, higher digital skill levels were found to be *positively* related with the achievement of positive outcomes and avoidance of negative outcomes (Vissenberg et al., 2022). While this is true for all the dimensions in our research, the volatile dimensions indicate that the developmental stages and growth curves at which young people develop their digital capabilities might also be a central element to consider. To understand this in more depth, it might be imperative to examine from the multifaceted construct which of the competences might develop first, how the dimensions are related, and how and when the dimensions are related to other forms of development. It could be that certain dimensions are closely linked to personality maturity while others are not (e.g., autonomy in choice of digital content (Hofmans et al., 2024)). Thus, for effective intervention development, our results emphasize the importance of promoting a higher level of core dimensions.

#### 4.3. Core DM-dimensions dependent on national context (external factor)

Lastly, the identification of a country effect was aligned with prior literature. Other studies have already pointed at potential differences in young people's use of digital devices across countries, and young people's ICT-behavior has been found to be influenced by family, culture, and social norms (Erumban & de Jong, 2006; Gracia et al., 2023; Lobe et al., 2011; Smahel et al., 2020; Van Everdingen, 2003). Therefore, some contribution to the overall index score might be expected in some countries where the capabilities are already practiced by family, peers, or taught in school, but not in other countries. In these results, Germany, Austria, and Greece had a small contribution. Surprisingly, Denmark and Slovakia did not show any importance in predicting the overall index score for digital maturity. These varying importance scores indicated that small country differences exist in young people's level of digital maturity, and the prediction of the overall index score is dependent on national context. However, to a small degree in comparison to the ten capabilities for digital maturity.

### 5. Limitation and future research

Our results obtained within this study are subject to some

limitations. First, the obtained results are limited to young people from European countries. There might be a need to investigate the findings in countries outside Europe as young people's digital maturity was found to be influenced by national context within European countries. The geographical scope was intentional to focus on countries, such as Germany, Austria, Denmark, Slovakia, and Greece. This might limit the transferability of our findings to other countries outside Europe. We did not measure demographic factors (i.e., socio-economic status (SES) and social factors (e.g., peer and family influence) for the respondents. However, these factors could have been useful to profile the countries to see the differences between them. Secondly, we did not explore the interaction between young people's capacities. The focus of the study was to examine the relative influence of the capabilities of digital maturity. This was enabled by the applied method that captured the individual predictive capability on the overall index score for digital maturity. Third, as this study is cross-sectional, our effects have not been explored from a longitudinal perspective. Digital maturity is a dynamic concept that might evolve over time, which means this study does not capture the developmental trajectory of digital maturity over time. This limits the knowledge on the developmental processes behind obtaining digital maturity.

These limitations can be addressed in future studies by exploring how generalizable these dimensions are to more valuable contexts outside Europe but also include countries that differ with respect to socio-economic status and social factors. Including more diverse countries, for instance countries within and outside Europe, would allow for testing the robustness of the obtained results for the dimensions of digital maturity. Moreover, we need to detect how young people's digital maturity develops over time. The core dimensions could be the target of an intervention that then examines how some of the dimensions spread to other dimensions over time. This will also allow to examine the interaction between identified dimensions. Not because the dimensions are the same, but because an intervention-based approach allows individuals to make new experiences that then lead to further processes of the development of digital maturity. This means researchers should develop hypotheses about such processes and test them in longitudinal designs, which can be used to test whether some dimensions develop first while others are relevant only if individuals have reached a certain level of maturity or have a certain level of online engagement, and interactions.

### 6. Conclusion

To conclude, the result of this paper deepens our understanding of the complex relationships and dependencies that exist between the digital maturity dimensions and young people's overall index score for digital maturity. Some of the dimensions were found to be more important, whereas other dimensions were found to be less important. These results provide a perspective on the dimension weights for digital maturity that can be further validated by other methods. Distinguishing this set of dimensions that show higher importance to the digital maturity index score allows for creating interventions and can be used for segmentation purposes that can help young people advance in their level of digital maturity by focusing on the most relevant aspects. Furthermore, we identified the marginal effects and how each of the dimensions change over a range of input values in relation to the overall index score. Here, some dimensions were found to be more volatile (stable) than others. This creates an understanding of where the most increase in the overall digital maturity score can be obtained. Lastly, we also examined whether the overall index score was dependent on the national context. The results showed small importance scores and some variations across countries were found when it comes to predicting young people's digital maturity index score.

**CRedit authorship contribution statement**

**Rikke Nyland Christensen:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Aqib Siddiqui:** Writing – review & editing, Methodology, Formal analysis. **Konstantina Valogianni:** Writing – review & editing, Methodology, Formal analysis. **Arnd Florack:** Writing – review & editing, Writing – original draft, Project administration, Investigation, Funding acquisition, Conceptualization. **Marco Hubert:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

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**Declaration of Competing interest**

The authors have no conflicts of interest to disclose.

**Appendix A. – The Digital Maturity Inventory (DIMI)**

**Table 3**  
DIMI items

Item	Variable
<i>When using a mobile device, I am online because I feel like I have to be online all the time (Reverse item). Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	autonomy_c1
<i>When using a mobile device, I am online because otherwise I feel like I am missing out on something (Reverse item). Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	autonomy_c2
<i>When using a mobile device, I have the feeling that it is controlling my life (Reverse item). Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	autonomy_c3
<i>When using a mobile device, I choose the content I want to see. Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	autonomy_w1
<i>When using a mobile device, I do the things that I like. Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	autonomy_w2
<i>When using a mobile device, I decide what I do. Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	autonomy_w3
<i>I know how to change the privacy settings (for example, deactivate cookies). Scale: Not at all true of me (1) – Not very true of me (2) – Neither true or untrue of me (3) – Mostly true of me (4) – Very true of me (5)</i>	literacy_1
<i>I know how to adjust the privacy settings of social media sites (for example, Instagram, Snapchat, TikTok). Scale: Not at all true of me (1) – Not very true of me (2) – Neither true or untrue of me (3) – Mostly true of me (4) – Very true of me (5)</i>	literacy_2
<i>I know how to store photos, documents, or other files in the cloud (for example, Google Drive, iCloud). Scale: Not at all true of me (1) – Not very true of me (2) – Neither true or untrue of me (3) – Mostly true of me (4) – Very true of me (5)</i>	literacy_3
<i>When using a mobile device, I learn new things. Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	growth_1
<i>When using a mobile device, I learn something useful. Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	growth_2
<i>When using a mobile device, I learn new skills. Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	growth_3
<i>When using a mobile device, I am very careful. Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	risk_1
<i>When using a mobile device, my own safety is very important to me. Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	risk_2
<i>When using a mobile device, I make sure to be careful. Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	risk_3
<i>When using a mobile device, I ask others for help when I have a problem. Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	support_1
<i>When using a mobile device and I don’t know what to do, I ask others for help. Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	support_2
<i>When using a mobile device and there is a technical problem, I ask others for help (for example, a friend, parent, sibling). Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	support_3
<i>When using a mobile device and I have problems with others on the internet, I get help. Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5).</i>	support_4
<i>When using a mobile device and I become annoyed or upset online, it takes me a long time to feel better (Reverse item). Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	emotion_n1
<i>When using a mobile device and I become annoyed or upset online, I stay in a bad mood for a long time (Reverse item). Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	emotion_n2
<i>When using a mobile device and I become annoyed or upset online, there are only few things that can make me feel better (Reverse item). Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	emotion_n3
<i>When using a mobile device and somebody criticizes me online or in a text, I immediately react without considering the consequences (Reverse item). Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	emotion_a1
<i>When using a mobile device and a message makes me angry, I react too quickly and then later regret the way I responded (Reverse item). Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	emotion_a2
<i>When using a mobile device and somebody insults me, I try to get back at them (Reverse item). Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	emotion_a3
<i>When using a mobile device, I watch my language when I disagree with someone, so that what I say doesn’t come across as mean. Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	respect_1
<i>When using a mobile device, I care about the feelings of others. Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	respect_2
<i>When using a mobile device, I make sure that pictures I post or send of other people will not insult them or get them into trouble. Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	respect_3
<i>When using a mobile device, I respect the opinions and knowledge of others. Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	respect_4
<i>When using a mobile device, I use it to improve life in my neighborhood, town or world. Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	citizenship_1
<i>When using a mobile device, I use the internet to support campaigns for issues like environmental protection or to spread awareness for climate change. Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	citizenship_2
<i>When using a mobile device, I use it to stand up for things that really matter in the world. Scale: Never = 1, Rarely (2), Sometimes (3), Often (4), Always (5)</i>	citizenship_3

## Appendix B. – Reliability Analysis of the Digital Maturity Dimensions across Countries

**Table 4**  
Reliability statistics

Dimension	Number of items	Standardized Cronbach's alpha					
		Overall	Austria	Germany	Greece	Denmark	Slovakia
Autonomous Choice to Use Mobile Devices	3	0.81	0.80	0.84	0.74	0.76	0.86
Autonomy within Digital Contexts	3	0.81	0.79	0.83	0.73	0.90	0.78
Digital Literacy	3	0.83	0.83	0.83	0.80*	0.83	0.84
Individual Growth in Digital Contexts	3	0.85	0.82	0.87	0.81	0.86	0.86
Digital Risk Awareness	3	0.88	0.87	0.88	0.86	0.88	0.91
Support-seeking Regarding Digital Problems	4	0.85	0.85	0.88	0.78	0.78	0.84
Regulation of Negative Emotions in Digital Contexts	3	0.87	0.87	0.88	0.90	0.85	0.85
Regulation of Impulses in Digital Contexts	3	0.81	0.80	0.84	0.78	0.81	0.80
Respect towards Others in Digital Contexts	4	0.83	0.83	0.85	0.72	0.79	0.80
Digital Citizenship	3	0.87	0.85	0.88	0.83	0.88	0.88

\* Only two items were used for Greece.

**Table 5**  
Mean scores for the ten capabilities of digital maturity across countries

Dimension	Austria	Germany	Denmark	Greece	Slovakia	Overall
Autonomous Choice to Use Mobile Devices	3.36	3.37	3.16	3.23	3.09	3.33
Autonomy within Digital Contexts	4.32	4.24	4.21	3.87	4.17	4.24
Digital Literacy	3.83	3.76	3.59	3.77	3.94	3.79
Individual Growth in Digital Contexts	3.54	3.52	3.46	4.01	3.67	3.57
Digital Risk Awareness	3.87	3.84	3.56	4.08	4.01	3.87
Support-seeking Regarding Digital Problems	3.62	3.60	3.38	3.85	3.14	3.60
Regulation of Negative Emotions in Digital Contexts	3.62	3.62	3.38	3.53	3.56	3.60
Regulation of Impulses in Digital Contexts	3.76	3.68	3.47	3.39	3.53	3.67
Respect towards Others in Digital Contexts	4.09	4.07	3.79	4.02	3.73	4.04
Digital Citizenship	2.34	2.35	2.41	2.97	2.50	2.42

## Appendix C. – Data Preparation and Methods

### Data Pre-processing procedure

The data pre-processing followed several steps. First, we checked if any of the observations contained missing values on the capabilities ( $N = 0$ ). Only participants between 12 and 18 years old who use mobile devices were able to complete the online survey. This was followed by averaging the items for each observation into a single dimension score. The items for Autonomy in Digital Contexts, Regulation of Negative Emotions in Digital Contexts, and Regulation of Impulses in Digital Contexts were reversed before they were averaged into a single score. In Appendix B, Table 4, the reliability statistics for each dimension across countries are shown. The mean and standard deviations for each dimension are shown in Appendix B, table 5.

### Random Forest Training, Testing, and Parametrization

Our model is built from random forests and relies on a non-parametric method that models the data by means of multiple decision trees. This approach allows for flexibility and non-linear relations between the dimensions and the predicted outcome (Breiman, 2001; Denil et al., 2014). It has already proven to be useful for determining the importance of variables in different prediction scenarios (Best et al., 2021, 2022; Gufroni et al., 2021).

To train our model, the data was split into a training (80 %) and test dataset (20 %). We used stratified sampling to select the observations and ensure that all countries were represented in both the training and the test datasets. On the training set, we used a grid-search to check different model specifications to optimize the performance and determine the best model parameters. With 80 % of the data, we trained the models with repeated cross-validation (5-folds) and the following hyperparameter specifications: 500, 1000, and 2000 trees (i.e., ntrees), number of variables at each split (i.e., mtry) from 2 to 10, and a stopping criterion (i.e., node-size - the minimum number of observations in each terminal node) set to 10. To evaluate the performance, the metrics R-squared, MAE, and MSE was used to optimize the explained variability in the data to guide the learning process and select the best model fit.<sup>2</sup> The final model was estimated with 500 trees, mtry = 3, and node-size = 10.

<sup>2</sup> Each model was re-estimated several times without convergence issues using the CARET package in R Kuhn, M. (2008). Building Predictive Models in R Using the caret Package. *Journal of Statistical Software*, 28(5), 1–26. <https://doi.org/10.18637/jss.v028.i05>.

## Appendix D. – Pseudocode for generating CFI

### Input:

Data:

- Dataset with observations on the 10 dimensions ( $x_j$ )

Parameters:

- Dimensions = 10
- Reference score = 5
- Sensitivity score ( $k$ ) = 0.5

### Begin

Step 1: Initialization

- Normalize each dimension  $x_j$  in the dataset (min-max normalization)
- Normalize the reference score to match the data scale

Step 2: Compute distances for each dimension to the reference score

For  $j$  from 1 to Dimensions Do

For each observation  $i$  in  $x_j$  Do

Compute fuzzy score:

$$CFI_{ij} = k / (k + |x_{ij} - \text{reference score}|)$$

EndFor

EndFor

Step 3: Aggregate fuzzy scores using a product t-norm

For each observation  $i$  Do

Compute  $CFI_{\text{overall}} = \text{Product of } CFI_{ij} \text{ across all dimensions } j = 1 \text{ to } 10$

EndFor

Step 4: Generate overall Composite Fuzzy Indicator (CFI)

Return vector of  $CFI_{\text{overall}}$  for all observations

### End

## Data availability

Data will be made available on request.

## References

- Aslanova, I. V., & Kulichkina, A. I. (2020). Digital maturity: Definition and model. *Proceedings of the 2nd International Scientific and Practical Conference - Modern Management Trends and the Digital Economy: From Regional Development to Global Economic Growth (Mide 2020)*, 138, 443–449.
- Atkinson, C., & Newton, D. (2010). Online behaviours of adolescents: Victims, perpetrators and web 2.0. *Journal of Sexual Aggression*, 16(1), 107–120. <https://doi.org/10.1080/13552600903337683>
- Ayllón, S., Barbovski, M., Casamassima, G., Drossel, K., Eickelmann, B., Ghețau, C., et al. (2020). ICT usage across Europe: A literature review and an overview of existing data. <https://doi.org/10.6084/m9.figshare.12906737>.
- Bandura, A. (1989). Social cognitive theory. In R. Vasta (Ed.), *Annals of child development* (Vol. 6, pp. 1–60). Six theories of child development.
- Beaulac, C., & Rosenthal, J. S. (2019). Predicting university students' academic success and major using random forests. *Research in Higher Education*, 60(7), 1048–1064. <https://doi.org/10.1007/s11162-019-09546-y>
- Best, K. B., Gilligan, J. M., Baroud, H., Carrico, A. R., Donato, K. M., Ackerly, B. A., & Mallick, B. (2021). Random forest analysis of two household surveys can identify important predictors of migration in Bangladesh. *Journal of Computational Social Science*, 4, 77–100. <https://doi.org/10.1007/s42001-020-00066-9>
- Best, K., Gilligan, J., Baroud, H., Carrico, A., Donato, K., & Mallick, B. (2022). Applying machine learning to social datasets: A study of migration in southwestern Bangladesh using random forests. *Regional Environmental Change*, 22(2). <https://doi.org/10.1007/s10113-022-01915-1>. Article 52.
- Bond, M. H., Lu, Q., Lun, V. M. C., & Smith, P. B. (2020). The wealth and competitiveness of national economic systems moderates the importance of big five personality dimensions for life satisfaction of employed persons in 18 nations. *Journal of Cross-Cultural Psychology*, 51(5), 267–282. <https://doi.org/10.1177/0022022120924756>
- Breiman, L. (2001). Random forests. *Machine Learning*, 45, 5–32. <https://doi.org/10.1023/A:1010933404324>
- Crone, E. A., & Dahl, R. E. (2012). Understanding adolescence as a period of social-affective engagement and goal flexibility. *Nature Reviews Neuroscience*, 13(9), 636–650. <https://doi.org/10.1038/nrn3313>
- Denil, M., Matheson, D., & De Freitas, N. (2014). Narrowing the gap: Random forests in theory and in practice. *International Conference on Machine Learning*, 32(Cycle 1), 32.
- Echterhoff, G., & Higgins, E. T. (2017). Creating shared reality in interpersonal and intergroup communication: The role of epistemic processes and their interplay. *European Review of Social Psychology*, 28(1), 175–226. <https://doi.org/10.1080/10463283.2017.1333315>
- Erumban, A. A., & de Jong, S. B. (2006). Cross-country differences in ICT adoption: A consequence of culture? *Journal of World Business*, 41(4), 302–314. <https://doi.org/10.1016/j.jwb.2006.08.005>
- European Commission. (2019). *2nd survey of schools – ICT in education – Objective 1 – Benchmark progress in ICT in schools, final report*. P. Office.
- European Commission. (2024). European digital rights and principles. <https://digital-strategy.ec.europa.eu/en/policies/digital-principles>.
- Eurostat. (2021). How many citizens had basic digital skills in 2021?. Retrieved 12/11/2024 from <https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20220330-1#:~:text=Back%20How%20many%20citizens%20had,basic%20digital%20skills%20in%202021%3F&text=In%202021%2C%2054%25%20of%20people,indicators%20published%20by%20Eurostat%20today>.
- Ferguson, A. M., Turner, G., & Orben, A. (2024). Social uncertainty in the digital world. *Trends in Cognitive Sciences*, 28(4), 286–289. <https://doi.org/10.1016/j.tics.2024.02.005>
- French, K. A., Dumani, S., Allen, T. D., & Shockley, K. M. (2018). A meta-analysis of work-family conflict and social support. *Psychological Bulletin*, 144(3), 284–314. <https://doi.org/10.1037/bul0000120>
- Friedman, J. H. (2001). Greedy function approximation: A gradient boosting machine. *Annals of Statistics*, 29(5), 1189–1232. <https://doi.org/10.1214/aos/1013203451>
- Gracia, P., Bohnert, M., & Celik, S. (2023). Digital inequalities and adolescent mental health: The role of socioeconomic background, gender, and national context. In *Research handbook on digital sociology*.
- Greenberger, E., Josselson, R., Knerr, C., & Knerr, B. (1975). The measurement and structure of psychosocial maturity. *Journal of Youth and Adolescence*, 4(2), 127–143.
- Greenwell, B. M., & Boehmke, B. C. (2020). *The R Journal*, 3434–3366 [https://rdrr.io/cran/vip/man/vi\\_permute.html](https://rdrr.io/cran/vip/man/vi_permute.html).
- Gufroni, A. I., Purwanto, P., Farikhin, F., Wibowo, A., & Warsito, B. (2021). Exploratory data analysis to identify the Most important feature of university admission test criteria using random forest and neural network algorithm. In *5th international conference on informatics and computational Sciences (Icicos)*. <https://doi.org/10.1109/Icicos53627.2021.9651757>
- Haddon, L., & Livingstone, S. (2017). Risks, opportunities, and risky opportunities: How children make sense of the online environment. In F. C. Blumberg, & P. J. Brooks

- (Eds.), *Cognitive development in digital contexts* (pp. 275–302). Elsevier. <https://doi.org/10.1016/B978-0-12-809481-5.00014-6>.
- Haug, S., Castro, R. P., Kwon, M., Filler, A., Kowatsch, T., & Schaub, M. P. (2015). Smartphone use and smartphone addiction among young people in Switzerland. *Journal of Behavioral Addictions, 4*(4), 299–307. <https://doi.org/10.1556/2006.4.2015.037>
- Helsper, E. J., & Smahel, D. (2020). Excessive internet use by young Europeans: Psychological vulnerability and digital literacy? *Information, Communication & Society, 23*(9), 1255–1273. <https://doi.org/10.1080/1369118x.2018.1563203>
- Hietajarvi, L., Mascheroni, G., Waechter, N., Järvinen, J., & Salmela-Aro, K. (2023). *Latent profiles of adolescents' digital skills across six European countries*.
- Hofmans, L., van der Stappen, A., & van den Bos, W. (2024). Developmental structure of digital maturity. *Computers in Human Behavior, 157*. <https://doi.org/10.1016/j.chb.2024.108239>
- Jiménez-Fernández, E., Sánchez, A., & Pérez, E. A. S. (2022). Unsupervised machine learning approach for building composite indicators with fuzzy metrics. *Expert Systems with Applications, 200*. <https://doi.org/10.1016/j.eswa.2022.116927>
- Jones, L. M., & Mitchell, K. J. (2016). Defining and measuring youth digital citizenship. *New Media & Society, 18*(9), 2063–2079. <https://doi.org/10.1177/1461444815577797>
- Juhász, T., Kálmán, B., Tóth, A., & Horváth, A. (2022). Digital competence development in a few countries of the European Union. *Management & Marketing, 17*(2), 178–192. <https://doi.org/10.2478/mmcks-2022-0010>
- Kesharwani, A. (2020). Do (how) digital natives adopt a new technology differently than digital immigrants? A longitudinal study. *Information & Management, 57*(2). <https://doi.org/10.1016/j.im.2019.103170>
- Kirwil, L. (2009). Parental mediation of children's internet use in different European countries. *Journal of Children and Media, 3*(4). <https://doi.org/10.1080/17482790903233440>
- Koch, T., Laaber, F., & Florack, A. (2024). Socioeconomic status and young people's digital maturity: The role of parental mediation. *Computers in Human Behavior, 154*. <https://doi.org/10.1016/j.chb.2024.108157>
- Kuhn, M. (2008). Building predictive models in R using the caret package. *Journal of Statistical Software, 28*(5), 1–26. <https://doi.org/10.18637/jss.v028.i05>
- Laaber, F., Florack, A., Koch, T., & Hubert, M. (2023). Digital maturity: Development and validation of the Digital Maturity Inventory (DIMI). *Computers in Human Behavior, 143*. <https://doi.org/10.1016/j.chb.2023.107709>
- Laaber, F., Koch, T., Hubert, M., & Florack, A. (2024). Young People's digital maturity relates to different forms of well-being through basic psychological need satisfaction and frustration. *Computers in Human Behavior, 152*. <https://doi.org/10.1016/j.chb.2023.108077>
- Law, D. M., Shapka, J. D., & Collie, R. J. (2020). Who might flourish and who might languish? Adolescent social and mental health profiles and their online experiences and behaviors. *Human Behavior and Emerging Technologies, 2*(1), 82–92. <https://doi.org/10.1002/hbe2.172>
- Livingstone, S., Haddon, L., Görzig, A., & Ólafsson, K. (2011). *Risks and safety on the internet: The perspective of European children: Full findings and policy implications from the EU Kids Online survey of 9-16 year olds and their parents in 25 countries*.
- Livingstone, S., & Helsper, E. (2007). Gradations in digital inclusion: Children, young people and the digital divide. *New Media & Society, 9*(4), 671–696. <https://doi.org/10.1177/1461444807080335>
- Livingstone, S., & Helsper, E. (2010). Balancing opportunities and risks in teenagers' use of the internet: The role of online skills and internet self-efficacy. *New Media & Society, 12*(2), 309–329. <https://doi.org/10.1177/1461444809342697>
- Livingstone, S., Mascheroni, G., & Staksrud, E. (2018). European research on children's internet use: Assessing the past and anticipating the future. *New Media & Society, 20*(3), 1103–1122. <https://doi.org/10.1177/1461444816685930>
- Livingstone, S., Mascheroni, G., & Stoilova, M. (2021). The outcomes of gaining digital skills for young people's lives and wellbeing: A systematic evidence review. *New Media & Society, 25*(5), 1–27. <https://doi.org/10.1177/14614448211043189>
- Livingstone, S., Ólafsson, K., Helsper, E. J., Lupiáñez-Villanueva, F., Veltri, G. A., & Folkvord, F. (2017). Maximizing opportunities and minimizing risks for children online: The role of digital skills in emerging strategies of parental mediation. *Journal of Communication, 67*(1), 82–105. <https://doi.org/10.1111/jcom.12277>
- Lobe, B., Livingstone, S., Ólafsson, K., & Vodeb, H. (2011). *Cross-national comparison of risks and safety on the internet: Initial analysis from the EU Kids Online survey of European children*.
- Majid, I. S. A., & Ahmad, T. (2022). Properties and some applications of fuzzy metric space. *Proceedings of Science and Mathematics*.
- Mano, R. (2021). The institutionalization of ICT and civic participation: Evidence from eight European nations. *Technology in Society, 64*. <https://doi.org/10.1016/j.techsoc.2020.101518>
- Mascheroni, G., & Ólafsson, K. (2016). The mobile internet: Access, use, opportunities and divides among European children. *New Media & Society, 18*(8), 1657–1679. <https://doi.org/10.1177/1461444814567986>
- Notten, N., Peter, J., Kraaykamp, G., & Valkenburg, P. M. (2009). Research note: Digital divide across Borders—A cross-national Study of adolescents' use of digital technologies. *European Sociological Review, 25*(5), 551–560. <https://doi.org/10.1093/esr/jcn071>
- Ólafsson, K., Livingstone, S., & Haddon, L. (2013). Children's use of online technologies in Europe. A review of the European evidence base. <http://eprints.lse.ac.uk/50228/>.
- Park, S., & Puranam, P. (2024). Vicarious learning without knowledge differentials. *Management Science, 70*(5). <https://doi.org/10.1287/mnsc.2023.4842>
- Reid Chasiakos, Y. L., Radesky, J., Christakis, D., Moreno, M. A., Cross, C., Hill, D., Ameenuddin, N., Hutchinson, J., Levine, A., Boyd, R., & Mendelson, R. (2016). Children and adolescents and digital media. *Pediatrics, 138*(5). <https://doi.org/10.1542/peds.2016-2593>
- Rodríguez-de-Dios, I., van Oosten, J. M. F., & Igartua, J. J. (2018). A study of the relationship between parental mediation and adolescents' digital skills, online risks and online opportunities. *Computers in Human Behavior, 82*, 186–198. <https://doi.org/10.1016/j.chb.2018.01.012>
- Rosic, J., Janicke-Bowles, S. H., Carbone, L., Lobe, B., & Vandenbosch, L. (2022). Positive digital communication among youth: The development and validation of the digital flourishing scale for adolescents. *Frontiers in Digital Health, 4*. <https://doi.org/10.3389/fgdh.2022.975557>
- Rousseau, A. (2024). Reciprocal relationships between adolescents' incidental exposure to climate-related social media content and online climate change engagement. *Communication Research, 51*(4), 415–438. <https://doi.org/10.1177/00936502231164675>
- Scholbeck, C. A., Molnar, C., Heumann, C., Bischl, B., & Casalicchio, G. (2020). Sampling, intervention, prediction, aggregation: A generalized framework for model-agnostic interpretations. *Machine Learning and Knowledge Discovery in Databases, 1167*, 205–216. [https://doi.org/10.1007/978-3-030-43823-4\\_18](https://doi.org/10.1007/978-3-030-43823-4_18). EcmI Pkdd 2019, Pt I.
- Shechtman, O. (2013). The coefficient of variation as an index of measurement reliability. In S. Doi, & G. Williams (Eds.), *Methods of clinical epidemiology*. Springer Series on Epidemiology and Public Health. [https://doi.org/10.1007/978-3-642-37131-8\\_4](https://doi.org/10.1007/978-3-642-37131-8_4).
- Smahel, D., Machackova, H., Mascheroni, G., Dedkova, L., Staksrud, E., Ólafsson, K., Livingstone, S., & Hasebrink, U. (2020). *EU Kids Online 2020: Survey results from 19 countries*.
- Stankovic, J. J., Marjanovic, I., Drezgic, S., & Popovic, Z. (2021). The digital competitiveness of European countries: A multiple-criteria approach. *Journal of Competitiveness, 13*(2), 117–134. <https://doi.org/10.7441/joc.2021.02.07>
- Statista. (2023). Country-level digital competitiveness rankings worldwide as of 2023. <https://www.statista.com/statistics/1042743/worldwide-digital-competitiveness-rankings-by-country/>.
- Statista. (2024). Number of mobile internet users worldwide from 2020 to 2029. <https://www.statista.com/forecasts/1146312/mobile-internet-users-in-the-world>.
- Subrahmanyam, K., Greenfield, P., Kraut, R., & Gross, E. (2001). The impact of computer use on children's and adolescents' development. *Journal of Applied Developmental Psychology, 22*(1), 7–30. [https://doi.org/10.1016/S0193-3973\(00\)00063-0](https://doi.org/10.1016/S0193-3973(00)00063-0)
- Thordsen, T., & Bick, M. (2023). A decade of digital maturity models: Much ado about nothing? *Information Systems and e-Business Management, 21*(4), 947–976. <https://doi.org/10.1007/s10257-023-00656-w>
- Thordsen, T., Murawski, M., & Bick, M. (2020). *How to measure digitalization? A critical evaluation of digital maturity models* responsible design, implementation and use of information and communication technology. *Skukuza, South Africa*.
- Tsitsika, A., Janikian, M., Schoenmakers, T. M., Tzavela, E. C., Ólafsson, K., Wójcik, S., Macarie, G. F., Tzavara, C., Richardson, C., & Consortium, E. N. A. (2014). Internet addictive behavior in adolescence: A cross-sectional Study in seven European countries. *Cyberpsychology, Behavior, and Social Networking, 17*(8), 528–535. <https://doi.org/10.1089/cyber.2013.0382>
- van Deursen, A. J. A. M., & van Dijk, J. A. G. M. (2019). The first-level digital divide shifts from inequalities in physical access to inequalities in material access. *New Media & Society, 21*(2), 354–375. <https://doi.org/10.1177/1461444818797082>
- Van Everdingen, Y. M. (2003). The effect of national culture on the adoption of innovations. *Marketing Letters, 14*(3), 217–232. <https://doi.org/10.1023/A:1027452919403>
- Vissenberg, J., d'Haenens, L., & Livingstone, S. (2022). Digital literacy and online resilience as facilitators of young people's Well-being? A systematic review. *European Psychologist, 27*(2), 76–85. <https://doi.org/10.1027/1016-9040/a000478>
- Williams, H. T. P., McMurray, J. R., Kurz, T., & Lambert, F. H. (2015). Network analysis reveals open forums and echo chambers in social media discussions of climate change. *Global Environmental Change-Human and Policy Dimensions, 32*, 126–138. <https://doi.org/10.1016/j.gloenvcha.2015.03.006>
- Williams, C., Schallmo, D., Lang, K., & Boardman, L. (2019). Digital maturity models for small and medium-sized enterprises: A systematic literature review. *The International Society for Professional Innovation Management (ISPIM)*.
- Zhu, C. Y., Huang, S. Q., Evans, R., & Zhang, W. (2021). Cyberbullying among adolescents and children: A comprehensive review of the global situation, risk factors, and preventive measures. *Frontiers in Public Health, 9*. <https://doi.org/10.3389/fpubh.2021.634909>