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Digital competence in adolescents and young adults: a critical analysis of concomitant variables, methodologies and intervention strategies

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Digital competence (DC) has received increased attention in society, politics and research in recent years. A particular emphasis has been placed on the importance of empowering adolescents and young adults to become digitally competent and sovereign adults, and that this should be achieved, for example, with the help of educational learning approaches. To provide an overview of research trends in this field, we conducted a scoping review and critical analysis of relevant literature on 15–25-year-olds' DC, determining factors and consequences under research, methodological preferences and evaluated intervention strategies. Both descriptive techniques and quantitative classification methods (latent class and latent profile analyses) were used in summarising the state of the art. After screening 3605 scientific articles, two samples were further investigated: 230 articles on young people's overall DC and a subsample thereof covering 20 articles on intervention studies. There were four major findings: (1) Contrary to wide-spread expectations, the number of relevant publications on adolescents' DC displayed a flatter increase than the total growth of articles in the field. (2) A latent class analysis over concomitant variables revealed three subgroups of articles addressing study-specific, educational or so-called *digital divide* variables. Notably, little attention could be observed with respect to developmental aspects, including psychosocial variables, despite their critical importance for this age cohort. (3) A second classification of articles' research designs and methodological foci yielded three latent profiles: university students' DC level, secondary research on secondary students and DC as a predictor in university contexts. (4) Though most articles emphasised the importance of empowering young people in a digital world, only a few scientifically examined intervention concepts could be found, and these were extremely heterogeneous. We conclude that research on young people's DC, especially that related to fostering their digital abilities, should be intensified.

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Introduction

As adolescents and young adults will be challenged to cope with a broad spectrum of lifelong and intensifying learning needs resulting from growing *human-computer interactions*, this paper aimed at developing a coherent and more comprehensive, multidisciplinary understanding of digital competence in this age group. As estimated by the International Telecommunication Union (ITU), 75% of adolescents and young adults were connected to the internet in 2022, representing the largest age group of internet users worldwide (ten percentage points more than the rest of the population; ITU 2022). In many countries they also seem to use digital services and applications (e.g., social media) with above-average intensity and frequency (Initiative D21 e. V. 2021; ITU 2013). These so-called *millennials* and members of *Generation Z* are sometimes thought to acquire the necessary skills and abilities for navigating the virtual world *incidentally* through their frequent internet use and exchange of tips and tricks. However, numerous studies (Bogdanovskaya et al. 2020; Calvani et al. 2012; Porat et al. 2018; Soldatova and Rasskazova 2017) have shown a lack of in-depth understanding in this age group not only of the underlying technical aspects of the virtual world (e.g., being tracked over platforms and apps or being hacked) but also of risky (social) consequences like cyberbullying, addictive behaviour, social isolation and information security. A considerable number of researchers also believe that adolescents and young adults lack necessary digital skills, knowledge and attitudes (e.g., Sánchez-Caballé et al. 2020; Zhao et al. 2021). Discussing potential antecedents as well as outcomes, these researchers call for specific instruction on self-protection and development of self-regulatory digital abilities.

While these studies are of significant value, the existing body of research on the digital competence of adolescents and young adults is often fragmented, focusing on specific terms, age groups or narrow research objectives. To effectively enhance digital competence among adolescents and young adults and chart a course for future research, there is therefore a critical need for a comprehensive overview of the last decade's research. This study aims to investigate how digital competence has been measured, identify influencing factors and outcomes, analyse methodological approaches employed, explore existing intervention strategies and their efficacy, and assess the overall evolution of research in this domain.

Digital literacy, a narrower concept mostly restricted to technical aspects of human-computer interaction, has been described as a cultural technique of continuously increasing importance (van Laar et al. 2017). As new use cases emerge, additional learning requirements are needed for full participation in societal life. Although all members of society are affected by these additional requirements, the focus of educational research is primarily directed toward specific subpopulations. Aged people, university students, people with functional deficits and those in specific professions (beyond the information and communication technology sector, e.g., Krumsvik 2022) have been the primary target of research. For the time being, young people in other educational- or non-educational settings (e.g., vocational training programmes, employment) seem to be underrepresented or even omitted. Where in most professions these learning requirements were conceptualised and performed as in-house trainings for specific skills, and thus with limited goals (Bergson-Shilcock 2020; van Laar et al. 2020), pupils' and teachers' education was mainly taken up by educational curricula and didactic research (Erstad et al. 2021).

Starting with an optimisation of the fundamental technical aspects, akin to reading capabilities in elementary school, the initial skill-oriented conception of digital competence has experienced a significant enhancement by incorporating aspects such as information seeking, critical source verification, privacy management, data protection and social behaviour in virtual spaces (e.g., netiquette, cyberbullying). Meanwhile, digital literacy (Buckingham 2010; Gilster and Glister 1997) and digital competence (first and mostly used in policy papers; see Ilomäki et al. 2011; 2016) are used in diverse research contexts, countries and educational science traditions with varying meanings (Spante et al. 2018). Alternative terminologies include computer and information literacy, information and communication technology (ICT) literacy, internet skills, (social) media literacy and 21st-century skills. These concepts, as Wuyckens et al. (2022) point out, lack shared definitions, especially when considering interdisciplinary perspectives. To avoid mere terminological discussions, we will provisionally use 'digital competence' (DC) as an umbrella term to describe skills, knowledge and attitudes of indispensable importance in a digitised world, encompassing related terms and concepts inclusively. It includes the 'confident, critical and responsible use of, and engagement with, digital technologies for learning at work and for participation in society' as formulated by the European Commission in their recommendations on key competences for lifelong learning (European Commission 2019). Comprehensive overviews of terminology usage, existing definitions and frameworks of DC and related terms can be found in various sources (e.g., Audrin and Audrin 2022; Ilomäki et al. 2011; Spante et al. 2018; Wuyckens et al. 2022). Most of these approaches focus on four issues: information retrieval and processing, production of online content, responsible and ethical standards in ICT usage, and ICT utilisation in communication (e.g., Siddiq et al. 2016).

Attempts to systematise relevant subskills, mutual relations to other cultural techniques, measurement and educational requirements for students and educators, have been undertaken by frameworks (Tinmaz et al. 2022; Mattar et al. 2022) such as DigComp, the European Digital Competence Framework for Citizens (Brande et al. 2016; Carretero et al. 2017; Ferrari 2013) and DigCompEdu 2018 (Redecker and Punie 2017). These frameworks are usually constructed as a product of expert discussions, sometimes via consensus conferences, sometimes using Delphi methodology, but always working on a definitory, theoretical level. Reviews, whether undertaken as scoping or systematic reviews, also seek to compress the central lines of reasoning among their selected publications by segregating and grouping publications' elementary attributes in a meaningful way (e.g., Ilomäki et al. 2016).

The study presented here does not aim to add an additional term or super-concept of DC. Nor does it constitute a further attempt at definition or conceptualisation of the issue. Instead, using statistical techniques that allow for some degree of overlap between different concepts or use of terminology while incorporating measurement error into group segregation (a latent variable approach), we aim to provide an overview of the research landscape of young people's DC and offer a novel perspective distinct from previous methodological approaches. This goal will be pursued by directing the focus on (a) registering the concomitant variables that are discussed, measured and analysed in relation to DC, be they determining factors or consequences of different levels or differing qualities of DC, and (b) methodological issues of the articles dealing with DC (measuring instruments, sample characteristics, number of items or subdimensions, statistical procedures, etc.).

Given the long-lasting conviction of a quasi-natural DC among the generation of so-called 'digital natives' (sensu Prensky 2001a, 2001b), the review focused on young people aged 15–25 (see 'youth'; Sawyer et al. 2018), for which educational research uses the label of *(older) adolescents* and *young adults* (hereafter AYA). Young people in this age range are in a critical

developmental stage characterised by significant physical, cognitive, emotional and social changes (Hurrelmann and Quenzel 2018, Sawyer et al. 2018). They also often make important decisions regarding their education and career paths, and may face significant life transitions, such as leaving home, entering the workforce or starting college (Hurrelmann and Quenzel 2018; Seiffge-Krenke et al. 2008; 2010; 2016). Thus the 10-year-age-focus of our study reflects the potential heterogeneity of developmental processes during this period, and extends beyond a one-sided selection of articles from only secondary education (e.g., Haddon et al. 2020; Livingstone et al. 2021; Scherer and Siddiq 2019; Siddiq et al. 2016; Stopar and Bartol 2019) or university contexts (e.g., Farias-Gaytan et al. 2022; Gutiérrez-Ángel et al. 2022; Litiņa and Miltuze 2021; Saltos-Rivas et al. 2022; Sánchez-Caballé et al. 2020; Sillat et al. 2021; Spante et al. 2018; Zhao et al. 2021).

In this critical analysis, we aim to identify studies measuring DC in AYA, explore trends in concomitant variables under research and methodological approaches and subsequently screen for intervention strategies designed and implemented for the purpose of improving DC in AYA. The analysis is thus analogous to the structure and concept of a scoping review (Peters et al. 2020). Only intervention studies offering minimal empirical standards (e.g., pre-post measurement of predefined outcome) should be regarded. It was deemed unrealistic to conduct a meta-analysis over interventional studies, as educational evaluations are seldom designed as randomised trials. Nevertheless, calculating comparable effect size measures and visualising their precision (both techniques taken from this approach) might be helpful in gaining an overview of the state of the art in the digital education of AYA.

Understanding the current state of research on AYA's DC, methods, concomitant variables and interventions can help to identify requirements and recommendations for future research, as well as complement and update existing reviews with similar objectives (e.g., Audrin and Audrin 2022; Farias-Gaytan et al. 2022; Pettersson 2018; Stopar and Bartol 2019). We have formulated the following research questions to meet our aforementioned goals and guide our empirical overview of the research landscape:

- RQ1: How did the research landscape of 15–25-year-olds' DC develop over the last decade?
- RQ2: What are the main lines of thought and substantial concepts in the research landscape?
  - RQ2a: What are the concomitant variables that have been studied as potential determining factors or as consequences of various levels specifically of AYA's DC?
  - RQ2b: What methodological approaches are commonly used in AYA's DC measurement research?
- RQ3: What approaches to foster AYA's DC are evaluated in the literature on intervention studies?

Method

The methodology of this study's literature search and systematic scoping review was based on Arksey and O'Malley's (2005) six-step framework, further developed by Levac et al. (2010). To bring forward the overview of the research landscape in AYA's DC, both descriptive techniques and innovative quantitative classification methods were used in summarising the state of the art. To achieve this, all included papers had to be coded on a predefined catalogue of quantifiable criteria. Latent variable modelling was then used to gain insight into the research landscape and identify potential blind spots and deficits.

As a first step of analysis, a larger set of articles (hereinafter sample 1) providing broad results on the measurement, determining factors and consequences of AYA's DC was analysed. Following this, all papers of sample 1 dealing with the evaluation of intervention strategies for the target group (hereinafter sample 2) were scrutinised in a narrative manner, but also using some elements from meta-analysis.

Literature search: search strategy, eligibility criteria and study selection. Five types of search terms were used to conduct a review of the research landscape: terms that would (1) identify articles about studies with AYA; (2) identify quantitative studies that measure DC and/or (3) try to improve AYA's DC; (4) identify different types of digital technologies; and (5) identify various types of skills and competences. The search terms were based on previous reviews (e.g., Haddon et al. 2020; Sánchez-Caballé et al. 2020) and expert consultations. They were then tested in several databases. Combinations of descriptors (see Supplementary Table S1) were applied after an initial pilot trial.

Five databases were selected covering psychological, educational or health aspects (e.g., excessive internet use), educational aspects and social and health sciences literature: PsycINFO [Ovid], MEDline [Ovid], ERIC [Ovid], Scopus, and Web of Science. The articles' titles, keywords and abstracts were scanned for the search terms. The systematic scoping review of the databases was conducted in November and December 2021 and identified articles in English or German that had been published between 2010 and 2021. Additionally, a second search on Google Scholar for the terms 'digital competence' and 'adolescents' or 'young adults' was performed to identify other publications of interest that were not indexed in the selected databases. The first 500 results (as sorted by relevance by Google Scholar, 2010–2021, 30.11.2021, citations excluded) were reviewed for relevance. A snowballing technique was used to identify further studies not covered by the other techniques.

The inclusion criteria presented in Table 1 were chosen based on the aims of the paper. Due to rapid technological changes, for example, the changing focus and evolution of social media definitions (see Aichner et al. 2021), publications were limited to 2010–2021. Studies focusing exclusively on technical psychometric aspects of measurement were excluded.

A total number of 5712 results were identified from the initial databases. Removal of duplicates ($n = 2107$) resulted in 3605 unique articles. A random sample of 50 articles was selected for a pilot testing of source selectors (Peters et al. 2020). Four researchers independently took the decision to include or exclude each article from this random sample. Cohen's kappa as a reliability measure ranged from $\kappa = 0.73$ to $\kappa = 0.85$ (pairwise comparisons to principal rater), signalising good to excellent agreement (Fleiss et al. 2003). Deviating decisions were analysed and the coding manual was reformulated. The initial study selection was performed by screening the titles and abstracts. A total of 2714 out of 3605 articles were removed, mainly because no relevant information on AYA's DC was provided (79%) or there was no focus on the target group (14%). Records that could not be found in full-text ($n = 27$) were removed, resulting in 864 eligible full-text articles. The remaining articles were downloaded and screened. This led to the exclusion of another 635 articles which dealt with topics other than AYA's DC (43%), lacked appropriate measurement (26%) or included study samples outside of the defined age range (23%). Studies that investigated AYA with some overlap to our chosen age range (15–25 years) were included if the sample's mean age fell within this range. Studies providing results divided by age group were included only for the cohorts covering the defined age range.

The final set of articles (sample 1; listed in Supplementary Table S2) consisted of 230 journal articles reporting quantitative

Table 1 Eligibility screening: Inclusion and exclusion criteria.

Inclusion	Exclusion
• explicit focus on adolescents and young adults (15–25 years) • primary research or secondary data analysis (e.g., analysis of PISA data) • focus on measurement/assessment of DC and/or DC interventions with pre-post design in context of digital media (e.g., internet, social media, smartphone) • peer-reviewed journal articles • quantitative approach • published in English or German • papers published between 2010 and 2021 • peer-reviewed journal articles • full-text available	• participants outside of age range (e.g., pre-adolescents, elderly) • focus on a broader definition of screen time (e.g., tv, gaming) or media competence (e.g., books, magazines, radio, tv) • conference proceedings, editorial materials, book reviews, data papers, letters, meeting abstracts, • non-peer-reviewed journal articles (newspaper articles, magazine articles, editorials, opinion pieces, essays, etc.) • papers published before 2010 or papers with data collection before 2007 • non-English or non-German publications • qualitative approaches • review articles[a] • validation studies

[a]Reviews were initially included in the search and then later excluded to avoid thematic duplication of publication intent.

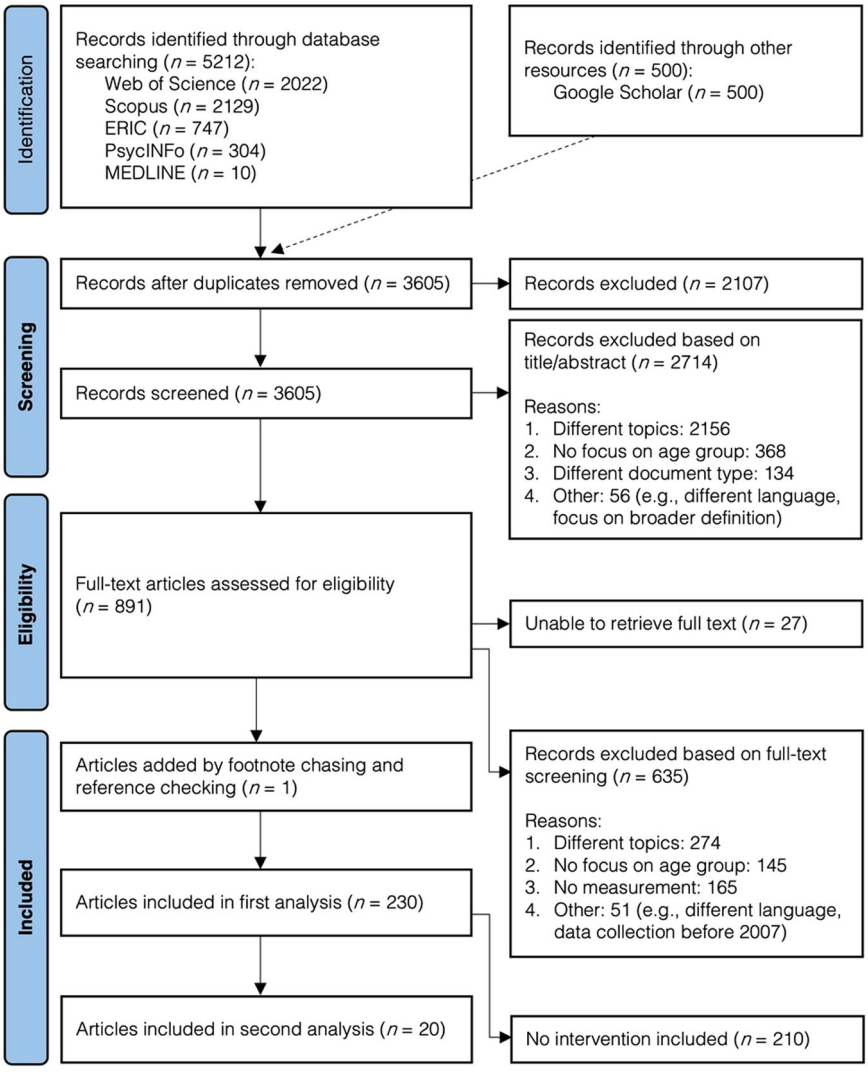

Fig. 1 PRISMA flow diagram of selected papers. Flowchart according to the PRISMA Consort 2020 version by Page et al. (2021).

data on AYA's digital abilities. Of these, 20 intervention studies with a pretest-posttest measurement design formed sample 2 for further analysis. The complete selection process can be depicted from the PRISMA-flowchart (PRISMA-ScR; Page et al. 2021; Tricco et al. 2018) in Fig. 1.

Quantitative approaches. For further analysis, the authors had a priori defined characteristics of interest. Most additional characteristics represented attributes that could be judged for existence/absence (1/0 values). The scientific field of the articles was determined via the Semantic Scholar research tool for scientific

literature, which provides an AI-based classification of articles. Of special interest for RQ2a were the concomitant variables, which were coded differentiating their role as predicting variables for AYA's DC, or as outcomes potentially associated with differing states or levels of AYA's DC. Concept use and terminology, and information about data collection, sampling and statistical analysis could thus be counted to answer RQ2b. Overviews of the necessary categorisation of concomitant variables and statistical analyses are presented in Supplementary Tables S3 and S4 (for taxonomy, see also Scheerder et al. 2017).

Analysing time trends of the publication landscape. Scientific journals have increased in their number and (since the dynamic development of the open-source movement) also in their extent (Gu and Blackmore 2016). Analysing time trends of a specific publication scene without normalising to general trends therefore would run the risk of misinterpretation. A specific analysis to judge the growth of research on AYA's DC must standardise in some way the annual number of papers. The whole set of all scientific journals covering the issue of DC spans a 'hidden population' (Salganik and Heckathorn 2004) and is not accurately countable, because some journals might potentially publish such issues while not having received or accepted any respective manuscripts during the observation period. Therefore, the set of those journals having published at least three articles of sample 1 was chosen as a comparison standard. This might be seen as a proxy for the development in the complete research scene on ICT issues and human behaviour.

The annual number of relevant publications in the year 2010 was set as index = 100, from which subsequent deviations were expressed as percentages. An analogous index was calculated for the total sum of all manuscripts published in those 16 scientific journals, which contributed at least three publications to sample 1. Thus, the resulting two growth curves could be compared to determine the relative weight of the AYA DC as a research topic within a broader context of human behaviour in the context of ICT technologies.

Segregating groups of publications. Selected papers were treated as sampling units. Beyond more traditional descriptive statistical methods (calculation of proportions, analysis of contingency tables) and beyond specific normalisation techniques (see above), some more sophisticated classification algorithms were used. We describe these here.

We chose hidden mixture model techniques to segregate the sampling units into groups with a maximum similarity of group members within the group and maximum dissimilarity between groups. The number of groups to be differentiated and the measure of (dis-)similarity are the most important decisions to be taken in this process. There are many classification algorithms available to perform this task. The wide-spread use of cluster analysis is usually performed in a two-step procedure: determining the number of clusters and then optimising membership of a sampling unit to exactly one cluster. However, the problem remains that a sampling unit could be comparably similar to more than one cluster. Latent Class Analysis (LCA) does not suffer from such an assumption of complete and disjunct separation. Its basic idea is different: a set of variables (assume 10 dichotomous characteristics of published articles) measured in a sufficiently large sample results in a 2**10-dimensional cross table. LCA aims at reproducing the cell frequencies of this high-dimensional cross table by determining a much smaller set of model parameters. For each category of each variable, the indicativeness of a certain answer for membership in a specified latent class g is estimated. The probabilities of this sampling unit (together with a second parameter set describing the estimated size of the latent class) belonging to each of the estimated latent classes can then be calculated. The number of necessary latent classes is decided by comparing various fit indices. The group membership (if needed) is decided according to the maximum membership probability. The adequacy of the calculatory solutions can also be pursued by likelihood-ratio tests, which measure the improvement of introducing an additional latent class for the aimed reproduction of the original raw data.

If the set of variables to separate groups consists of nominal and continuous measurement levels, the idea of an LCA can be broadened to a latent profile analysis (LPA), which uses, beyond parameters for the class sizes and category-specific indicativeness of a specific answer to each of the classes, a latent profile (means and standard deviations) of the hidden groups for all continuously measured data.

The respective multivariate analyses were performed using Mplus rel. 8.6. Other statistical analyses were performed using R 4.1.1.

Meta-analytic techniques for the compaction of intervention studies (sample 2). Meta-analysis has become the accepted standard to pack the results of experimental studies and their replications into a single, more stable measure of the 'true' effect size of a specific intervention strategy. For studies using a continuous outcome measure (e.g., a sum over self-administered items in a questionnaire), Cohen's *d* (Borenstein et al. 2009) is the standard to express effect size. Meta-analysis, then, under certain prerequisites, amalgamates the *d* values of numerous studies into a single overall measure.

For the 20 studies in sample 2, we did not aim to calculate a common effect size, as the goals and methods of the intervention studies were expected to be very heterogeneous, and the methodological standards of randomised clinical trials were mostly not met. However, to gain an overview of interventions applied to foster AYA DC, a common metric for the reported intervention effects seemed helpful. Most articles did not provide Cohen's *d* or other effect size measures. If possible, in these cases we calculated *d* from given parameters (mean, std. dev., mean std. error, *t*-statistic, etc.). This procedure should not be interpreted as an effect size calculation justifying a meta-analysis, not least because the studies had differing research designs. Instead, plotting these 'proxy *d* values' against a measure of precision (here: sample sizes) enabled a visual inspection of reported efficacies (see Fig. 8). This idea is similar to the method of drawing funnel plots (Sterne and Egger 2001), though our goal was not to decide on potential publication bias. Rather, this plot may be understood as a graphical display of the complete picture of intervention studies, no matter which outcome variable was chosen and without differentiating for design issues (simple pre-post comparison, use of deliberately chosen control groups or use of randomly assigned experimental groups).

Results

Our results are presented in the order of the research questions they aim to answer. After giving descriptive characteristics of sample 1, profiles of the two latent class (resp. profile) analyses are presented and named according to their most salient characteristics. Articles covering interventional strategies on AYA's DC constitute the last part of the results section.

RQ1: How did the research landscape develop during the last decade? Sample 1 contains 230 articles from 59 different countries (five continents). According to each first author's affiliation, nearly half of the studies were conducted by European researchers (47.8%). Almost a third were conducted by Asian researchers

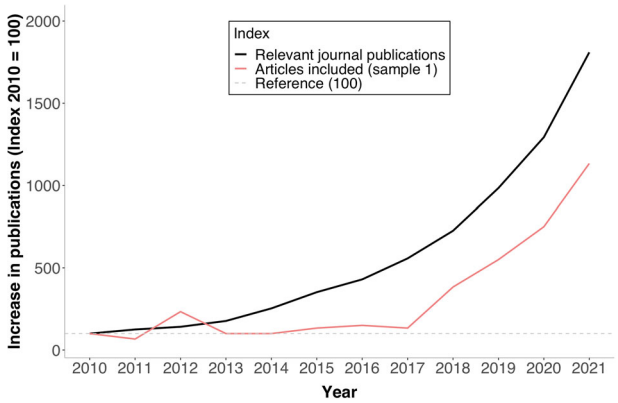

Fig. 2 Annual publications indexed to the year 2010. Number of annual publications in the field of AYA's DC research increased from 2010 to 2021 not as steep as total publications of related relevant journals.

(31.3%). Broken down by country, Turkey (9.6%), Spain (8.3%), the United States (7.9%), China (5.7%) and Germany (4.8%) are the most productive countries on our topic. Of a total of 230 articles, 229 were published in English; one was published in German (<1%). Unsurprisingly, most articles were published in the scientific field of Education (71.3%), followed by a substantially smaller proportion of articles in Psychology (14.3%), Economics (5.7%) and Computer Science (3.9%; see Supplementary Table S5 for a larger overview of study characteristics).

Articles of sample 1 stemmed from 150 different peer-reviewed journals, pointing at a broad distribution of the issue of AYA's DC over different journals. The journals with the highest numbers of articles on AYA's DC are Computers & Education (7%, $n = 17$), Education and Information Technologies (4%, $n = 10$), Sustainability (4%, $n = 9$), Computers in Human Behavior (3%, $n = 6$) and Education Sciences (3%, $n = 6$). The 16 journals that contributed at least three publications to sample 1 are listed in Supplementary Table S5.

As depicted in Fig. 2, the number of annual publications in the field of AYA's DC increased from six articles in 2010 to 68 articles published in 2021, an eleven-fold increase (index: 100–1133). However, the total publishing activities in the selected 16 journals during the same period increased by a factor of more than 18 from 1377 (index = 100) articles to 24,821 articles (index = 1810). Thus, the relative weight of research on AYA's DC actually fell when compared to all issues of the relevant publishing scene.

RQ2: What are the main lines of thought and substantial concepts in the research landscape? In sample 1, a total of 48 different terms and phrases were observed which describe or define DC and related constructs in AYA's DC research. It should be noted that many authors use multiple terms synonymously in their publications. The most frequently used term is 'digital competence' (18.9%), followed by 'digital literacy' (15.4%), 'ICT competence' (11.2%) and 'ICT skills' (8.4%). In one-third of the selected articles, the applied DC term is not further defined (32.6%). By contrast, in 57.4% of the articles, DC terms are defined with reference to research and/or political programmes. Only in one-third of sample 1, the research terms or goals are embedded in at least one reference framework. Most consulted frameworks are based on the European Digital Competence Framework for Citizens (DigComp): 13 articles refer to DigComp 2.1 (Carretero et al. 2017), 12 refer to DigComp (Ferrari 2013; later identified as DigComp 1.0), 8 mention the DigCompEdu framework (Redecker and Punie 2017) as theoretical basis, and 4 refer to DigComp 2.0 (Brande et al. 2016).

RQ2a: What are typical concomitant variables in AYA's DC research? By analysing sample 1, we found over 380 concomitant variables in the subject of DC research, of which over half (200) were ICT-related in nature (e.g., satisfaction with a hybrid learning course, online privacy practices). Nearly identical terms with minor variance in spelling and/or meaning were summarised and categorised in 18 types of variables (see Supplementary Table S3).

As shown in Fig. 3 (black line), most authors discuss sociodemographic- (44.8%, 103 articles) or study-specific variables in the context of their research on DC (e.g., time of measurement, DC subdimensions, 37.4%, 86 articles). In sample 1, the educational level of participants (16.1%) as well as their academic setting (14.8%), ICT usage habits (13.9%) and attitudes towards ICT (13.0%) is of interest in over 30 out of 230 articles. Economic variables, academic performance and psychosocial characteristics are seldom studied (all <6%).

Clustering of articles due to their handling of concomitant variables. Latent class analysis over concomitant variables handling reached a minimum BIC and adjusted BIC fit index for three latent classes. Though the Vuong-Lo-Mendell-Rubin Likelihood Ratio Test and Lo-Mendell-Rubin adjusted Likelihood Ratio Test signalise only marginally significant test statistics ($p < .10$) compared to the two-class solution, a meaningful progress in entropy and substantive reasoning convinced us to interpret the three classes solution.

The largest group (62.5%, orange dashed line in Fig. 3) most closely resembles the overall average, from which the other two groups clearly deviate. Situational characteristics (43.2%) with specific research questions requiring special methodologies and/or dealing with narrow focus (e.g., subdimensions of the concept of DC) are slightly overrepresented in this latent class. Cognitive competences (11.6%) enabling or hindering DC are discussed more often. Sociodemographic variables (23.2%) are a relatively neglected issue in this group. Accordingly, this group was called '*DC in situational contexts with study-specific variables*' (STUDSPEC).

The second largest group (blue dashed line in Fig. 2) comprised 23.0% of the selected articles. Because educational setting (38.4%), educational level (36.2%) and family background (26.1%) are types of variables frequently discussed in this group, it was labelled '*DC in context with education and pedagogical variables*' (EDUPED). Social (19.4%) and economic variables (17.2%) as well as educational performance (19.2%) are also overrepresented in this group. Articles belonging to EDUPED also tend to discuss sociodemographic variables more often (75.5%).

The smallest group (grey, dot-dashed line) represents 11.7% of articles. These mostly discuss sociodemographic variables (90.5%) as well as ICT usage (78.3%), IT access (62.0%) and ICT experience (47.0%) in the context of DC. Because this group deals with research on (inequal) access and use of IT applications and the internet (Castells 2002) in relationship with DC (second- and third-level digital divide; see Scheerder and Rasskazova 2017), it was named '*DC in context of digital divide variables*' (DIGDIV). This is in accordance with the nomenclature introduced in the 1990s.

RQ2b: What methodological approaches are used in AYA's DC measurement research? Further analysis of the data collection methods and sample descriptions reveals that more than half of the articles (58.7%) refer to previously published DC scales or

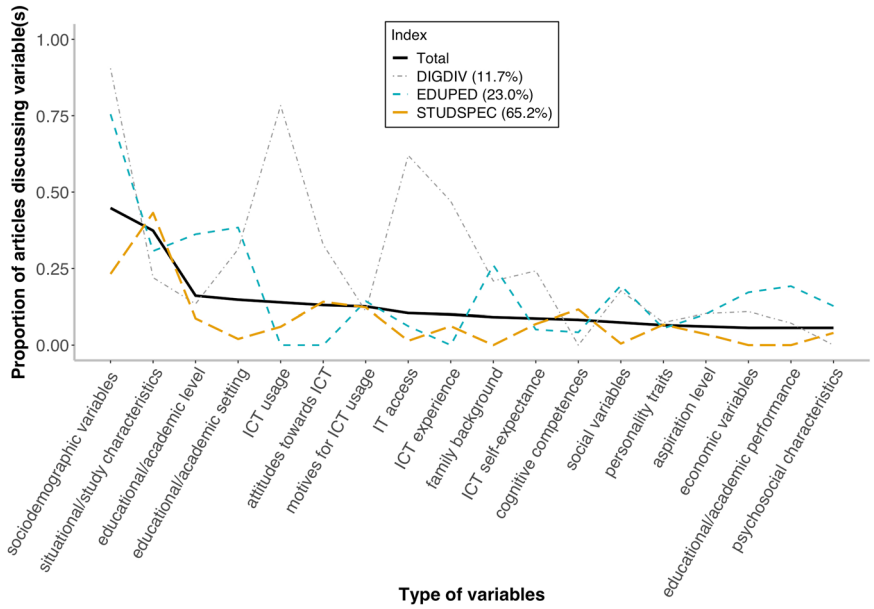

Fig. 3 Proportions of sample 1 articles discussing certain types of variables according to their latent class. Latent classes were named based on their most salient characteristics: *DC in situational contexts with study-specific variables* (STUDSPEC), *DC in context with education and pedagogical variables'* (EDUPED) and *DC in context of digital divide variables* (DIGDIV). 'Total' represents the 230 articles of sample 1.

tools in their analyses. Of these studies, 39.1% include ad hoc constructed measuring instruments. Assessment tools are, for the most part, self-assessment scales (94.9%). Only a few researchers use performance tests (6%) or knowledge/scenario-based tests (4.6%). Some articles do not provide any information on the measuring instrument used ($n = 5$) or type of measurement ($n = 14$).

On average, DC is measured with 27.11 items ($SD = 25.49$). Nearly half of the presented measurement instruments (46.5%) consist of more than 20 items. Some of the authors report on validity indicators (34.9%), whereas the majority (65.1%) do not mention the validation of the measuring instrument used. Reliability measures (e.g., Cronbach's alpha) are reported more frequently (67.7%).

Most (56.8%) of the articles included do not contain information about sampling strategies. In 18.3% of the studies a random sampling technique was chosen. A large range in sample size with a lower bound of 13 participants up to nearly 400,000 participants could be observed. However, most samples studied are medium in size and range from 101–500 participants (48.3%). Most of the researchers do not report the mean age of their participants (47.8%). If mentioned, AYA participants are on average 19.55 ($SD = 2.92$) years old. In line with the mean age, study samples are mainly of higher education students (71.3%), followed by secondary school students (23.0%), vocational education students (2.6%) and (un-)employed participants (1.3%). The study samples are either roughly equally distributed with respect to gender (37.8%) or unbalanced with preference for females (36.5%). Only a few articles include unbalanced samples with preference for males (5.7%). One fifth of all studies (20.0%) do not include information on participants' gender.

Most studies (87.0%) report on primary research results, whereas researchers of 30 articles used existing data sources (13.0%). The most commonly used statistical analyses are descriptive statistics (57.0%) and group comparisons or correlational analyses (53.0%), whereas prognostic models (regression models; 35.2%) and classification analyses (8.3%) or item response theory (IRT) analyses (2.2%) are less common. A majority of researchers investigate DC only as the outcome (64.8%) or as the predictor variable (21.3%), whereas 13.9% do both.

Clustering of articles by their methodological approaches. Latent profile analysis was used to identify subgroups of articles within sample 1 based on a set of nominal, continuous and ordinal method variables (e.g., study design, sampling technique, sample size, assessment of DC, statistical analyses). Most variables introduced in the previous chapter were dummy-coded by a priori defined attributes (see Supplementary Table S4 and Fig. 4). According to information criteria (AIC, BIC and adjusted BIC), a substantial improvement of model fit was reached by incorporating a second and a third latent class. Further classes (Vuong-Lo-Mendell-Rubin Likelihood Ratio Test and Lo-Mendell-Rubin adjusted Likelihood Ratio test) could not significantly improve the classification solution.

Profiles of latent classes and a total sample profile are visualised in Fig. 4. The largest latent class (53.9% of articles; see Fig. 5) is characterised by a high rate of studies on university students' (95.6%). DC is always regarded as the outcome (100%), mostly analysed with simple descriptive statistics (72.0%) or group comparisons / correlational analyses (61.0%). Sample sizes are comparatively small with 25% of studies reporting an $N \leq 100$. The number of DC dimensions under research was significantly higher than in the other latent classes ($M_{ARUS\text{-}outcome} = 3.60 \pm 2.55$; $M_{SECRES} = 2.54 \pm 1.80$; $M_{ARUS\text{-}predictor} = 2.20 \pm 1.75$; all contrasts $p < 0.05$, t-test). This class was called '*Articles reporting on university students DC level*' (ARUS-outcome).

The second largest latent class comprised 24.3% of the sample (see Fig. 6) and mostly consists of articles on secondary school students (70.3%, 0% higher education context). The use of existing databases (mostly PISA-based studies, 15 articles) dominates this group (60.7%). Due to the international field-work procedures, 56.6% of the articles in this latent class report a sample size of more than 1000 participants. Gender distribution in the samples is mostly balanced (67.3%). DC is examined both as the outcome (69.8%) and as the predictor (40.8%). The number of concomitant variables is highest in this latent class ($M_{SECRES} = 4.11 \pm 2.87$; $M_{ARUS\text{-}predictor} = 3.06 \pm 2.07$;

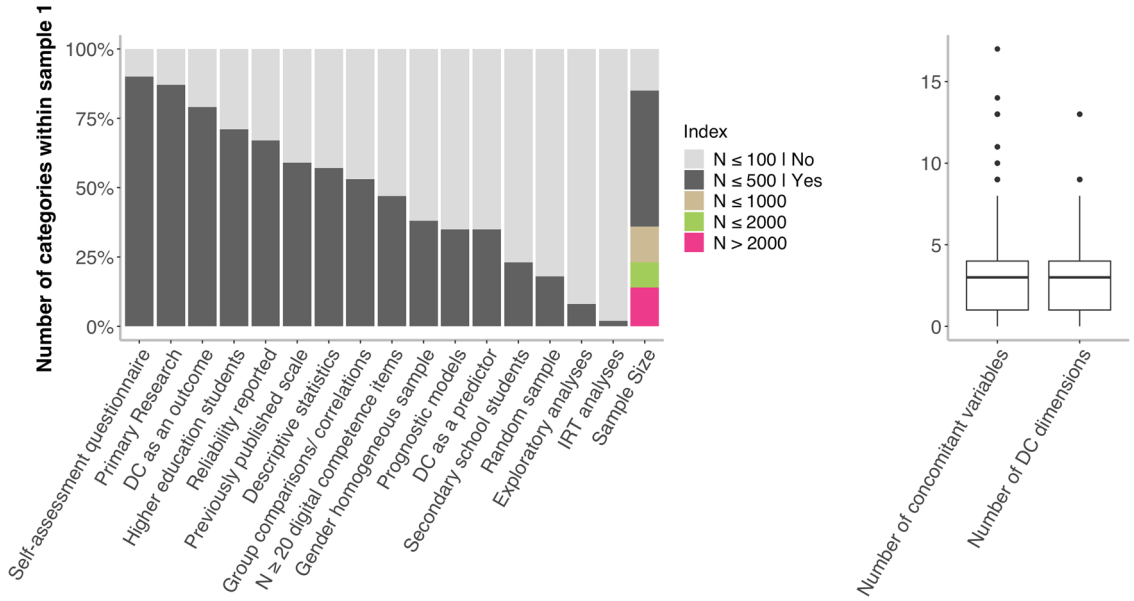

Fig. 4 Proportions of sample 1 articles reporting certain types of methodological variables ($N = 230$). Methodological variables are ordered by frequency of occurrence (total, all latent classes).

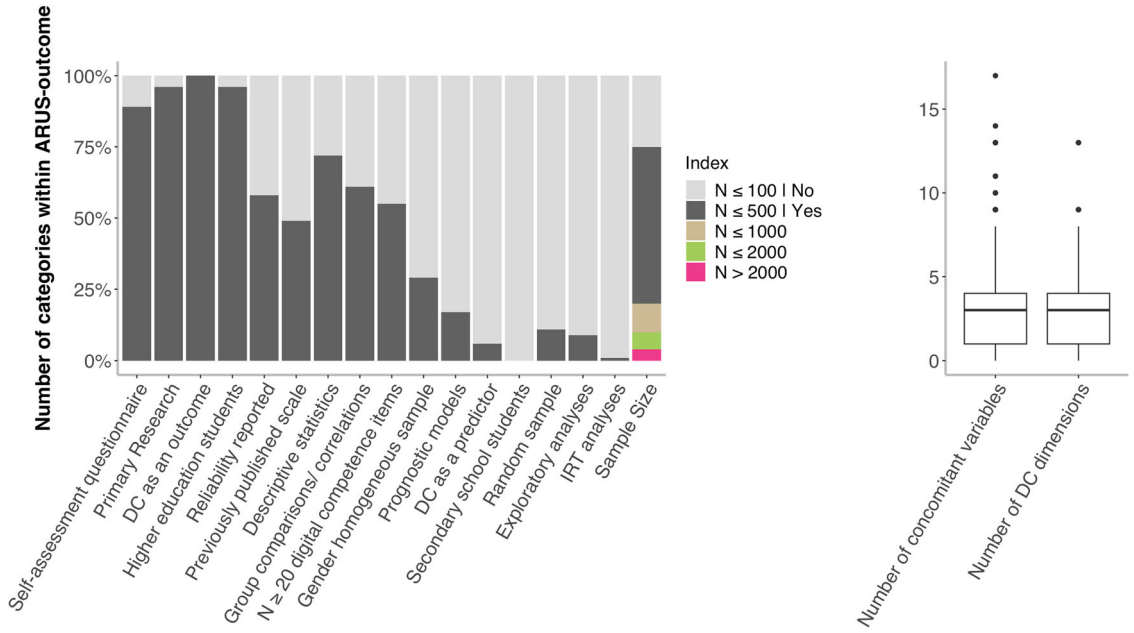

Fig. 5 Proportions of articles reporting methodological approaches in latent class ARUS-outcome ($n = 124$). Latent classes were named based on their most salient characteristics: *Articles reporting on university students DC level* (ARUS-outcome). Methodological variables are ordered by frequency of occurrence in all 230 sample 1 articles (for an overview of all latent classes see Fig. 4).

$M_{ARUS\text{-}outcome} = 3.10 \pm 2.94$; all contrasts $p > 0.05$, t-test). This subgroup was called '*Articles presenting secondary research on secondary students*' (SECRES).

The smallest latent class comprises 21.7% of the articles (see Fig. 7). This subgroup of articles was called '*Articles reporting on the role of DC as a predictor in university contexts*' (ARUS-predictor). The following methodological variables characterise this group. University students (92.4%) are the main focus. The articles always report on DC as a predictor (100%). Accordingly, the most commonly used statistical analyses are prognostic models (57.8%). The smallest latent class in this analysis shows the lowest number of concomitant variables as well as the lowest number of DC dimensions under research (see Fig. 7).

Relationship between method variable subgroups and concomitant variable subgroups. A cross-classification of LCA groups and LPA groups was tested for independence by a traditional global chi-square test (see Table 2) yielding significant deviations from the independence assumption, $x^2(4, N = 230) = 10.68$, $p = 0.03$. Analysis of adjusted standardised residuals (Agresti 2007; Sharpe et al. 2019) in Table 2 yields a closer than random association between the ARUS-predictor articles and their use of study-specific concomitant variables, and an underrepresentation of study-specific concomitant variables in the SECRES group. SECRES has a closer association with EDUPED, the group of articles dealing with educational and pedagogical concomitant variables. A negative association of

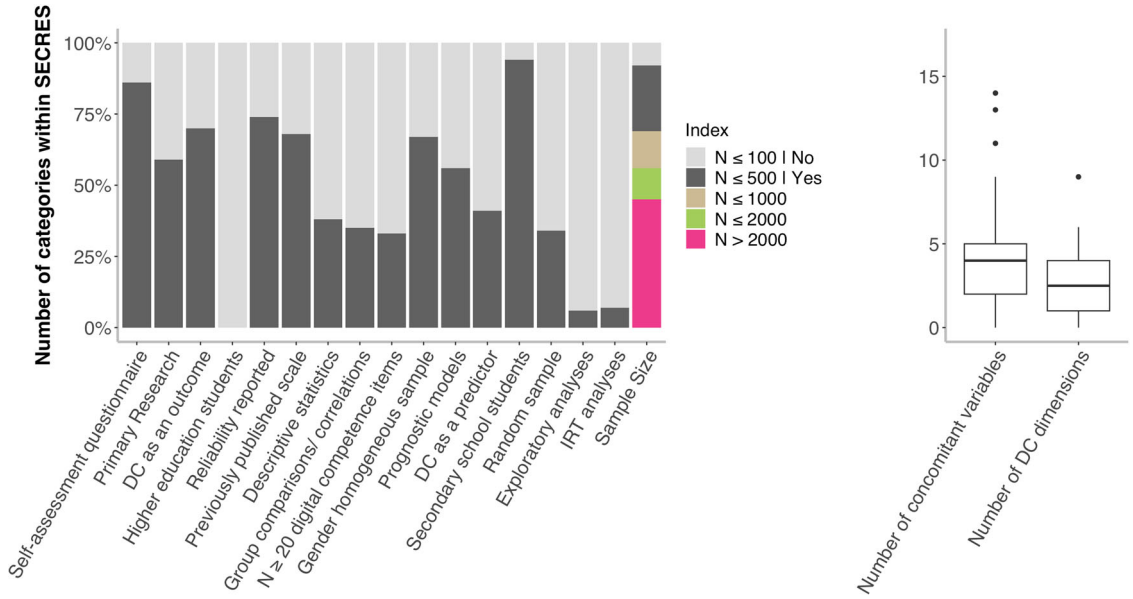

Fig. 6 Proportions of articles reporting methodological approaches in latent class SECRES ($n = 56$). Latent classes were named based on their most salient characteristics: *Articles presenting secondary research on secondary students"* (SECRES). Methodological variables are ordered by frequency of occurrence in all 230 sample 1 articles (for an overview of all latent classes see Fig. 4).

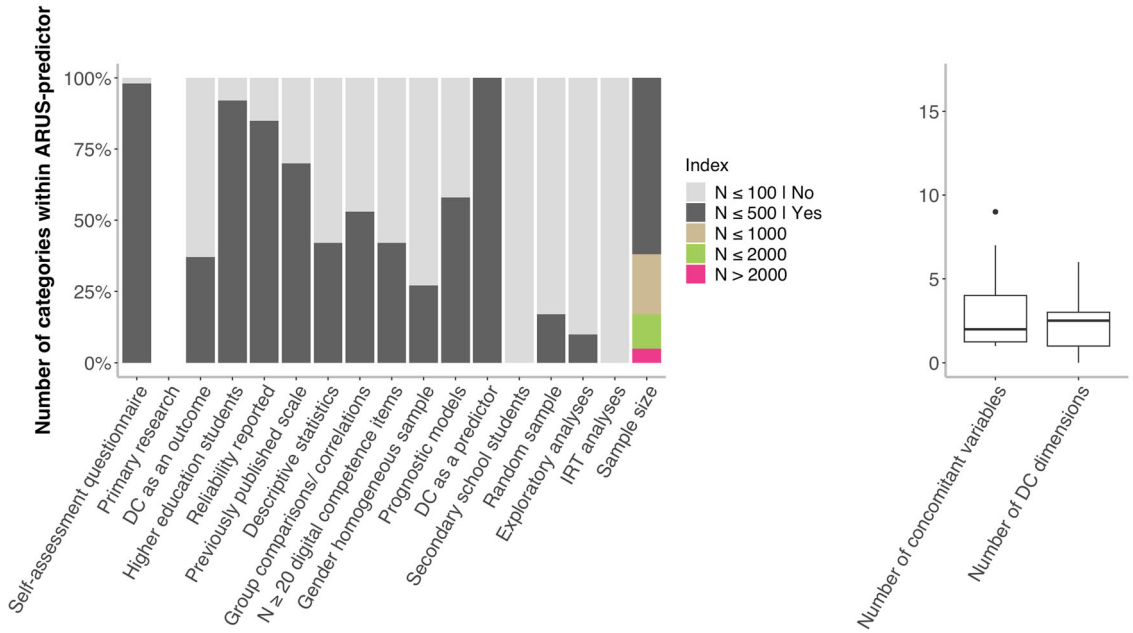

Fig. 7 Proportions of articles reporting methodological approaches in latent class ARUS-predictor ($n = 50$). Latent classes were named based on their most salient characteristics: *Articles reporting on the role of DC as a predictor in university contexts* (ARUS-predictor). Methodological variables are ordered by frequency of occurrence in all 230 sample 1 articles (for an overview of all latent classes see Fig. 4).

ARUS-predictor with DIGDIV use of concomitant variables seems plausible but reached only marginal significance ($p < 0.10$) probably due to limited sample size.

RQ3: What approaches to foster AYA's DC are evaluated in the literature? Sample 2 is a subsample of sample 1 and entails 20 articles evaluating DC interventions for AYA (see Fig. 2 for study selection process and Table 3 for a detailed overview of selected articles). It is notable that across the entire landscape of literature on AYA's DC, only 20 out of 230 included articles (8.7%) focus on this topic, though it is deemed highly relevant by researchers and policy (e.g., European Commission 2020, p. 6; Starčič et al. 2016). According to the first author's affiliation, seven of these articles were conducted by American researchers (35%), mainly between 2019 and 2021 (75%) in the scientific field of *Education* (60%).

We can group the selected intervention studies with respect to methodological criteria, target population, integration into educational settings, the specific intervention approaches/strategies, and the desired outcomes and their efficacy based on study results. Due to our inclusion criteria, all evaluation studies are based on a pre-post design. Five articles (25%) also report on quasi-experimental or experimental designs comparing control

Table 2 Frequencies of class probabilities.

LCA concomitant variables	LPA of methods used						
	ARUS-predictor		SECRES		ARUS-outcome		
	observed value	expected	observed value	expected value	observed value	expected value	Total
DIGDIV	2	5.9	8	6.6	17	14.6	27 (11.7%)
	4.0%[a]	−1.9[b]	14.3%	0.7	13.7%	1.0	
EDUPED	8	11.5	19	12.9	26	28.6	53 (23.0%)
	16.0%	−1.3	33.9%	**2.2**	21.0%	−0.8	
STUDSPEC	40	32.6	29	36.5	81	80.9	150 (65.2%)
	80.0%	**2.5**	51.8%	**−2.4**	65.3%	0.0	
Total	50 (100%)		56 (100%)		124 (100%)		230 (100%)

Contingency table displaying cell frequencies, column percentages (left), expected frequencies and adjusted standardised residuals (right).
[a]Column percentages;
[b]Adjusted standardised residuals (bold, if |value| > 1.96).

and experimental groups (see no. 1, 2, 8, 15 & 17 in Table 3). All but two researcher groups use self-report questionnaires to measure DC-related concepts as study endpoints. Two researcher groups use performance-based assessments (no. 1 & 15). More than half of the articles (55%) include ad hoc constructed measuring instruments. Six studies (30%) report on structured qualitative feedback assessments (e.g., semi-structured questionnaires, focus groups) in addition to their quantitative outcome measures.

Most of the samples receiving some interventions are rather small ($N \leq 100$; 65%); one-third are medium in size ($N = 101–500$; 35%). The majority of the study samples are composed of higher education students (80%; see formal tertiary education context in Table 3). Two articles report on interventions for secondary school students (no. 1 & 2; see formal secondary education context in Table 3). Another two articles do not further define the educational level of their AYA participants (no. 19 & 20; see non-formal context in Table 3). Nearly one-third of the study samples are roughly gender-balanced, more than one-third are unbalanced with preference for females, and nearly one-third do not include (explicit) information on participants' gender. One study, with a predominantly male sample residing in high poverty and high crime neighbourhoods, examines a mindfulness and emotion regulation DC programme targeted at AYA (no. 20). Another programme addressed adolescents with mental illnesses to improve their learning and problem solving through a group-based intervention (no. 19).

Objectives, contents, strategies and techniques of the intervention approaches covered a broad spectrum with a high level of heterogeneity. Five of 16 studies in formal tertiary educational contexts are (mandatory) formal semester courses embedded in the respective curriculum (no. 3–7). Half of the studies in sample 2 investigate their interventional ideas in tertiary education settings (no. 8–17) and focus on implementing topical learning content (e.g., cybersecurity knowledge), expanding learning concepts (e.g., blended learning) and/or innovative learning strategies (e.g., game-based learning). While some authors mainly describe new and essential educational content (no. 9 & 15), others present both topical contents and learning concepts that were transmitted to the new ICT technology: Blended learning (no. 10), computer-assisted learning (no. 11), e-learning (no. 13), distance learning with online platforms like Moodle (no. 14), privately hosted online learning communities (no. 17) and R-modules with specific datasets (no. 12) can be named here. Two articles introduce game-based learning strategies to foster DC (no. 8 & 16).

Also due to our inclusion criteria, all sample 2 studies present some approach to foster AYA's DC. Nevertheless, a large heterogeneity of the research landscape is evident when looking at researchers' desired outcomes or contents to be taught. A categorisation into seven subgroups seems appropriate: basic computer function skills; information skills; research skills; computational literacy; technology integration in teacher education; broader concepts of DC (with certain subdimensions); and specific skills. Two interventional approaches aim to teach simple basic computer functions like creating and saving electronic documents (no. 4) or the use of Microsoft Office programs (no. 3). Four strategies are designed to enhance information literacy and research skills, as well as information-based problem-solving (e.g., search behaviour, selecting keywords, evaluating the credibility of source content; no. 7, 8 & 15). Two authors present approaches to develop programming skills with a focus on either data manipulation and interpretation (no. 12) or algorithm and software testing skills (no. 9). Both approaches can be subsumed as computational literacy interventions. In contrast, other researchers (no. 5 10, 11 & 13) aim to train prospective teachers in using digital technologies to become digitally competent educators (e.g., planning resources, pedagogical knowledge, skills with technology). Only two educational interventions reflect a broader concept of DC in their learning materials (no. 14 & 16), for example subdimensions such as media-, information-, technology-, computer-, visual- and communication literacy (no. 16). A focus on quite specific skills and competences, such as online collaboration and participation skills (no. 17), smartphone skills (no. 19), skills for socio-politically engaged online behaviour (no. 20) or media competences (e.g., social media competence; no. 18) seem to be more common.

Regarding the latent classes covering concomitant variables (see sections on R2a and RQ2b), sample 2 studies mostly belong to the STUDSPEC (90%) and ARUS-outcome (85%) groups. Regarding the LPA over methodological variables, study no. 1 and 2 match the SECRES subgroup (secondary education samples). Probably due to its additional investigation of digital literacy skills and creative self-concept connections, study no. 8 matches the ARUS-predictor group. Regarding the LCA over concomitant variables, two studies (no. 7 & 17) match the EDUPED subgroup (discussion of personal and family background variables such as rurality and parents' education).

According to Fig. 8, there were only three studies reporting no or negligible success of their aspiration to improve DC or related subdimensions. The plot is heavily biased due to studies reporting disproportionate effects of their intervention approach. It should be kept in mind that study quality in Fig. 8 is only represented by the existence of a control group (triangle symbols). Further details of methodological quality are listed in Table 3. Most prominently, many of the studies report extremely large effect sizes.

Table 3 Studies presenting an intervention approach to foster AYA's DC (sample 2, $n = 20$).

				Sample			Digital competence		Efficacy
	Source	Type of intervention	Study design	N (% female)	Age	Educational background	Evaluation instrument	(Sub-) Dimensions	Cohen's d
	Formal secondary education context								
1	Ibieta et al. (2019)	Information problem solving using the internet (IPS-I) workshops, internet search software package, 11 weekly sessions, 90 min each	pre-post design, experimental & control group	52 (52%)	$M_{EG} = 14.9$, $M_{CG} = 15.2$	10th grade secondary school students	ad hoc performance test (students were asked to solve an information problem using a standard search engine)	e.g., quality of answers for each step, quality of final answer, search quality	medium effects between $d_{ppc2} \cong 0.55$–0.75
2	Perdana et al. (2020)	Online Laboratory Simulation with Problem-Based Learning (OLS-PBL) vs. Online Laboratory Simulation with Concept Mapping and Problem-Based Learning (OLS-CMPBL) vs. PBL model, six sessions of 60–90 min	pre-post design, two exp. groups & one control group, random sampling	97 (50%)	15–16	secondary school students, grade XI	ad hoc questionnaire based on Lankshear & Knobel (2008), 10 items	Internet searching; hyper textual navigation; content evaluation; knowledge assembly	no effect in PBL vs. OLS-CMPBL, large effects in PBL vs. OLS-PBL ($d_{ppc2} > 0.8$), OLS-PBL vs. OLS-CMPBL (d_{ppc2} » 0.8)
	Formal tertiary education context								
	a) semester courses embedded in the respective curriculum								
3	Buabbas et al. (2016)	*Informatics in Healthcare* course, mandatory, taught once a week, supported by computer laboratory sessions	pre-post design	171_{pre}/ 154_{post} (85%)	M = 17.8 (± 0.6)	first-year medicine, dentistry, and pharmacy students	Eze et al. (2011), modified version, 11 items + observational assessments	generic ICT skills; specific ICT skills	no effect size can be estimated
4	Papastergiou (2010)	*Computers*, a compulsory computer literacy course, 2 h weekly for 13 weeks, acquisition of basic ICT knowledge & skills	pre-post design	89 (46%)	$M = 18.4$	first-year physical education and sport science university students	Computer Self-Efficacy (CSE) scale (Torkzadeh et al. 2006), 25 items, Internet self-efficacy (ISE) scale (Hsu & Chiu, 2004), 19 items, both translated + feedback survey	computer self-efficacy; internet self-efficacy	medium ($d_{RM} \cong 0.75$) to large effects ($d_{RM} > 0.8$) in both dimensions
5	Romero-Tena et al. (2021)	Educational intervention: subject of *Information and Communication Technology Applied to Early Childhood Education*	pre-post design, two experimental groups (A before & B during COVID)	559 (94%)	A: 20–25 (76%), B: 20–25 (88%)	4th year early childhood education students	"DigCompEdu Check-In" (Cabero & Palacios 2019; Romero-Tena et al. 2021), adapted to Spanish and for students, 22 items	professional commitment; digital resources; digital pedagogy; evaluation and feedback; empowering student; facilitating competition digital students	medium effect group A vs. B ($d_{ppc2} \cong 0.45$)[a]

Table 3 (continued)

				Sample			Digital competence		Efficacy
	Source	**Type of intervention**	**Study design**	***N* (% female)**	**Age**	**Educational background**	**Evaluation instrument**	**(Sub-) Dimensions**	**Cohen's *d***
6	Schatteman and Liu (2020)	Undergraduate 3-credit course *Community Organizations in a Digital World*, critical thinking & technical skills, 16 weeks	pre-post design	44	-	undergraduate non-profit studies students	Young et al. (2018), number of items unclear + qualitative survey	digital literacy	large effect (d_{RM} » 0.8)
7	Ur Rehman and Al Awadhi (2013)	3-credit hour formal course of information and computing literacy as a required course for undergraduate students	pre-post design	144_{pre}/ 177_{post} (78%)[b]	-	university students with different majors	ad hoc questionnaire, number of items unclear	information skills; computing skills; research skills; overall skills	medium effect on overall skills ($d_{RM} \cong -0.75$)
	Formal tertiary education context b) new contents, strategies, or concepts								
8	Alt and Raichel (2020)	Gamified problem-based learning, platform named To-Be Education, three-month intervention	pre-post design, experimental & control group, longitudinal study	158 (90%)	$M_{EG} = 22.3$ (± 4.3), $M_{CG} = 21.8$ (± 1.9)	undergraduate education students	ad hoc questionnaire, 15(16) items + semi-structured interviews	access; analyse; evaluate; (create)	small to medium effects in all dimensions ($d_{RM} \cong$ 0.32–0.42)
9	Buckley et al. (2018)	Software engineering courses (data structures and algorithm or software testing course), one semester	pre-post design	65	*juniors and seniors*	undergraduate software engineering students	ad hoc questionnaire, based on two scenarios, 11 items	cybersecurity skills	large effect for juniors (d_{RM} » 0.8) and seniors ($d_{RM} > 0.8$)
10	Chaiyama (2019)	Blended learning model to foster 21st-century skills (e.g., digital literacy skills), 8 weeks long	pre-post design, purposive sampling	30	-	undergraduate physical education students	Information literacy skills test (Sriphan 2010), 50 items; Digital literacy skill test (Techataweewan & Prasertsin 2016), 54 items	information literacy skills; digital literacy skills (operation; thinking; collaboration; awareness)	large effects for information (d_{RM} » 0.8) and digital literacy ($d_{RM} > 0.8$)
11	Ekmekçi (2021)	Fourteen-week computer-assisted language learning (CALL) course	pre-post design	95 (73%)	21–24	undergraduate pre-service teachers	ad hoc questionnaire, based on TESOL-TSLT framework, 30 items + semi-structured interview	basic knowledge and skills in technology; integrating pedagogical knowledge and skills with techn.; feedback and assessment through techn.; using techn. for communication and collaboration	no effect in basic knowledge, medium ($d_{RM} \cong -0.74$) to large (d_{RM} » 0.8) effects in other dimensions

Table 3 (continued)

				Sample			Digital competence		Efficacy
	Source	Type of intervention	Study design	*N* (% female)	Age	Educational background	Evaluation instrument	(Sub-) Dimensions	Cohen's *d*
12	Farrell and Carey (2018)	Short-term (i.e., one laboratory period) intervention, three R-based modules, Project EDDIE (Environmental Data-Driven Inquiry and Exploration), basic programming skills	pre-post design	88	-	undergraduate ecology students	ad hoc questionnaire, 9 items	R, Microsoft Excel & programming proficiency; (confidence; likely future use)	small ($d_{RM} \cong 0.36$), medium ($d_{RM} \cong 0.48$) and large effects ($d_{RM} > 0.8$) in specific proficiencies
13	Hamutoglu et al. (2019)	Five-week e-learning course (Edmodo) to foster digital literacy skills	pre-post design	47 (53%)	-	undergraduate pre-service teachers	Digital Literacy Scale (Ng 2012), 17 items	attitude; technical; cognitive; social	no effect ($d_{RM} < 0.2$)
14	Kuatbekov et al. (2021)	Digital Etiquette e-learning course (Moodle online learning platform, Facebook group)	pre-post design	230[c] (65%)	21–25 (62%)[c]	graduate university students, different majors	ad hoc questionnaire, 25 items	digital literacy; content interpretation; content generation; digital awareness	no effect size can be estimated
15	McGrew et al. (2019)	Short curriculum intervention, two 75-min lessons in a 15-week semester course, evaluating the credibility of online content	pre-post design, experimental & control group, different order	67 (48%)	$M_{EG} = 18.4$, $M_{CG} = 18.8$, $M_{Total} = 18.6$	university students	performance test (McGrew et al. 2018), parallel versions of 4 tasks = 8 tasks	evaluating evidence; claims on social media; article evaluation; website evaluation	large effect for treatment average ($d_{ppc2} >> 0.8$)
16	Reddy et al. (2021)	Contextualised game-based digital literacy intervention (DLIP), six online modules of each 40 min, theoretical & self-testing components	pre-post design	126	-	first-year university students	digilitFj (Reddy et al. 2021), number of items unclear	media literacy; information literacy; technology literacy; computer literacy; visual literacy; communication literacy	medium effect ($d = 0.47$), effect size given
17	Welser et al. (2019)	Online learning community (OLC) in two sections of an introductory college course to develop socio-technical skills	pre-post design [d], experimental & control group	373 (57%)	-	first-year university students, social science course	ad hoc questionnaire (4 activities combined to an averaged index + increase in skills)[d], 8 items	collaborating; searching; sharing; participating in groups	no effect size can be estimated

Table 3 (continued)

				Sample			Digital competence		Efficacy
	Source	**Type of intervention**	**Study design**	***N* (% female)**	**Age**	**Educational background**	**Evaluation instrument**	**(Sub-) Dimensions**	**Cohen's *d***
18	Yevtushenko and Kovalova (2019)	Media education project (training course): different workshops and seminars to improve media literacy of future professionals	pre-post design	140_{pre}/ 112_{post} (81%)	17–23 (97%)	journalism students	ad hoc questionnaire, 26 items	technical information competence; information comp.; social information comp.; technical media comp.; media comp.; social media comp.	no effect size can be estimated
	Non-formal context								
19	Rodriguez-Villa et al. (2021)	Digital Opportunities for Outcomes in Recovery Services (DOORS): 8-week smartphone DC and skills course for youth with mental illnesses, 45 min per session, peer-to-peer setting	pre-post design	45	17–26	educational level not collected, participants with mental illness	ad hoc questionnaire, 5–7 statements per session	establishing core smartphone skills; building wellness habits; managing responsibilities; staying connected; keeping informed; expanding your knowledge; navigating safely; enjoying downtime	no effect size can be estimated
20	Sichel et al. (2019)	E-Responder: Youth Leadership Program (YLP), 24 stand-alone lessons to support youths' social media self-efficacy and prevent risky online behaviour	pre-post design, longitudinal pilot study	81 (majority male)	$M = 17.0$	educational level not specified; youth resided in high poverty/ crime neighbourhoods	Social Justice Self-Efficacy scale (Miller et al. 2009), adapted for online behaviour, 4 items + focus groups	social media self-efficacy	small effect ($d_{RM} \cong 0.25$)

Overview of sample 2 articles. Cohen's *d* was calculated to estimate the size of treatment effects, if possible (15/20). $d > 1$ was coded as $d \approx 0.8$. See "Method" section for details.
[a]The exact meaning/alias direction of the effect is unclear.
[b]A number of 144 participants answered the pretest, 177 answered the posttest.
[c]The total number of participants was unclear. Gender and age proportions (%) are therefore only approximations.
[d]At the second measurement point *change in skills* was measured instead of *skills*.

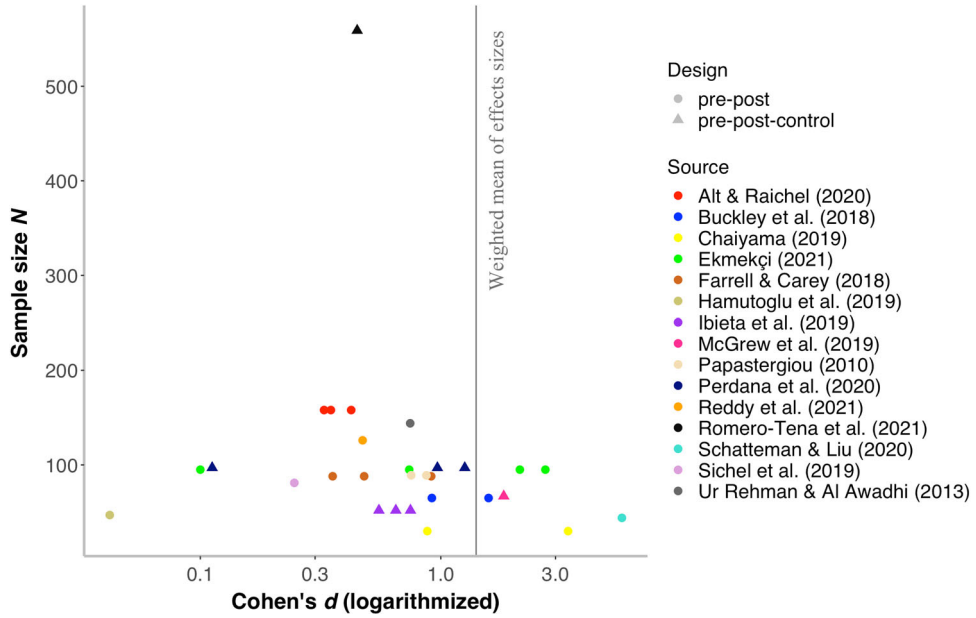

Fig. 8 Effect sizes for intervention studies by precision (sample size). This plot of logarithmized proxy *d* values against sample size, which serves as a measure of precision, allows for a visual inspection of the reported efficacies. A brief description on Cohen's *d* calculation can be found in the methods section.

Discussion

In this empirical overview we systematically explored 230 studies on 15–25-year old's DC (sample 1) in all uses of this term, after screening 3605 scientific articles. To address the constant call to foster AYA DC and develop new approaches in research (e.g., Pettersson 2018; Torres-Hernández and Gallego-Arrufat 2022), we additionally examined a subsample of 20 articles (sample 2) dealing with evaluated DC intervention approaches. Four major results occurred:

(1) The number of annual publications in the field of AYA DC research increased from 2010 to 2021, but not as steeply as the total publications of related relevant journals, meaning that DC-related research on young adults has not kept up with the general growth rate of scientific publications in the broader research area (RQ1).
(2) Looking at concomitant variables under research, we identified three subgroups of sample 1 articles using latent class modelling. The subgroups specifically address (a) study-specific (STUDSPEC), (b) educational and pedagogical (EDUPED), and (c) digital divide (DIGDIV) variables, as predictors or consequences of DC. Psychosocial variables (e.g., peer support, social influence, identity status) which play a major role in adolescence and emerging adulthood (e.g., Steinberg 2020) were seldom studied (RQ2a).
(3) Another classification according to articles' research design and methodological focus yielded three latent profiles: (a) university students DC level (ARUS-outcome), (b) secondary research on secondary students (SECRES), and (c) DC as a predictor in university contexts (ARUS-predictor; RQ2b). AYA's DC remains largely unexamined for young people who are (currently) not enrolled in an educational institution.
(4) Only a small number of articles on AYA's DC deal with the scientific evaluation of intervention concepts designed to foster DC (20 out of 230, sample 2). A large heterogeneity of the research landscape is evident when looking at researchers' intervention strategies, learning materials and desired outcomes (RQ3).

Contrary to wide-spread expectations, the priority of research on AYA's DC seems to have fallen during the last decade. Though there is a considerable growth on the annual number of publications dealing with AYA's DC, studies on other issues of human-machine interactions or questions of effective interface design outgrew the increasing number of papers on AYA's DC. The proxy indicator of literature development in human-machine interactions is in line with the findings of other authors regarding other topics of scientific research (Bornmann et al. 2021; Savage and Olejniczak 2022). Studies disregarding the general development of the research landscape thus fail to recognise the relative loss of urgency of the topic for researchers in the field. This is true even for studies published after the end of our observation period, even if the researchers chose different keywords and time restrictions (e.g., Audrin and Audrin 2022; Farias-Gaytan et al. 2022; Tinmaz et al. 2022).

An important objective of this overview was to identify lines of thought and substantial concepts in research on AYA's DC (see RQ2, RQ2a, RQ2b). As within the whole body of literature on DC (see Audrin and Audrin 2022; Mattar et al. 2022), a heterogeneous use of numerous different terminologies without reference to existing standards could be observed. This is not uncontroversial. For example, the notion of 'digital natives' has been criticised as a myth for various reasons: a heterogeneous definition and partly contradictory usage of the concept (Gallardo-Echenique et al. 2015); a disregard of social and cultural peer group norms essential for AYA's self-concept (Thornham and McFarlane 2011); and a disregard of specific use cases (e.g., inside/outside school; Wang et al. 2014). The appearance of the term 'digital natives' simply as a kind of age-cohort effect (Hobcraft et al. 1985) lacks a substantial theory when DC is implicitly postulated as a quasi-natural capacity of younger cohorts. According to our results, no other theory of acquiring DC and no commonly shared understanding of the meaning of DC has emerged between 2010 and 2021. Such heterogeneities point to a research landscape that seems to be undergoing a paradigm shift sensu Kuhn (see Anand et al. 2020; Koschmann 1996), and whose conceptual development is unfinished. Consequently, the research landscape seems haphazardly grounded on

theoretical elements from unconnected disciplines (see also Tveiterås and Madsen 2022).

Astonishingly, the biological, cognitive, social and identity-forming circumstances of the developmental period between the ages of 15 and 25 (e.g., biological maturation, cognitive development, peer support, fulfilment of developmental tasks; see Seiffge-Krenke 2008, 2010; Steinberg and Cauffmann 1996; Steinberg 2020) have no specific representation or impact on the research, though the selection procedure of sample 1 formulated these ages as an inclusion criterion. Age aspects only indirectly impact on theory building by using formal educational surroundings at the secondary and tertiary levels (see Table 3). This also applies to relevant concomitant variables associated with the developmental state of AYA. Even though they play a major role in this specific life period, we can see in the literature (e.g., Paluckaitė and Žardeckaitė-Matulaitienė 2019; Steinberg 2020; Trucco 2020) that cognitive variables (e.g., basic cognitive skills, higher-order thinking competences), social variables (e.g., social background, social capital), personality traits (e.g., self-concept, learning strategies) and psychosocial characteristics (e.g., peer support, help-seeking behaviours, identity status) are some of the least explored variables in the context of AYA DC research (see Fig. 3 and Supplementary Table S3).

Further referring to RQ2a, we could observe thematic foci other than developmental aspects regarding variables under research (see Fig. 3). Latent classes of concomitant variables discussed for AYA's DC demonstrate three subgroups: *DC in situational contexts of study-specific variables* (STUDSPEC), *DC in context of education and pedagogical variables* (EDUPED) and *DC in context of digital divide variables* (DIGDIV). A large group of articles (STUDSPEC with nearly two thirds) covers a broad spectrum of variables, but all focused on probability below $p = 0.25$. Sociodemographic variables and situational characteristics as exceptions also reach a probability below $p = 0.05$. This means that one cannot predict certain patterns of thematic interests from the group membership in STUDSPEC. The two other (smaller) latent classes share this picture: DIGDIV is characterised by increased ICT usage, IT access and to a smaller extent ICT self-experience, but follows the general pattern for all other variables. EDUPED only deviates from the general line in studying more often the family background of AYA and incorporating variables of the educational setting. This analysis not only enhances our understanding of research interests regarding the associations of DC in general, but also illuminates the specific thematic foci of researchers in the past decade in explaining the antecedents and outcomes of DC.

In a similar manner, our intention to decipher underlying patterns of interest based on the methodological approaches used by the paper's authors (RQ2b) resulted in three subgroups: *Articles presenting secondary research on secondary students* (SECRES), *articles reporting on university students' DC level* (ARUS-outcome) and *articles reporting on the role of DC as a predictor in university contexts* (ARUS-predictor). These groups were readily distinguishable based on their target populations, research methodologies and other methodological specifications (see Figs. 4–7). SECRES strictly focuses on students in secondary schools and never deals with students in tertiary education. As studies often use existing databases (e.g., PISA), the primary research is underrepresented here, the sample sizes are quite high and gender distribution is reported to be equal more often. Because large international school surveys like the Programme for International Student Assessment (PISA), the German National Educational Panel Study (NEPS) or the Monitor for ICT Integration in Flemish Education (MICTIVO) serve several topics, the space left in the self-administered questionnaires for a specific issue is quite limited, and the number of items (and subsequently dimensions) measuring DC in SECRES are therefore lower than average. Not surprisingly, SECRES has a closer association with EDUPED, indicating that variables related to education and pedagogy are more frequently examined (see Table 2).

In striking contrast to this picture, neither ARUS groups ever focus on students in secondary education. When DC is treated as a potential predictor of other topics (ARUS-predictor), prognostic models constitute most statistical methods. When DC is the outcome variable (ARUS-outcome), relatively few concomitant variables are included, and reliability of DC measurement is comparatively less often given. As anticipated and formerly criticised by other authors (Stopar and Bartol 2019), most of the selected studies have focused on university students. However, to our knowledge we were the first to investigate the research landscape of young people's DC without a specific focus on institutional affiliations (e.g., university students, secondary school students, prospective teachers).

The last objective of the study was to expose evaluated approaches to foster AYA's DC (see Table 3). Although numerous intervention strategies and learning programmes have been developed to improve aspects of AYA DC by a large number of educators and organisations (see Reddy et al. 2021) and the methodological minimum requirement for paper inclusion was set to a low threshold (pre-post quantitative measurement), only a small number of articles under study dealt with the evaluation of those educational interventions ($n = 20$, sample 2). This corroborates the hypothesis of an early stage of evidence-based research in the field of fostering DC in this age group. Otherwise, more trials on the efficacy of teaching interventions could have been expected. As also noted by Reddy et al. (2021) for non-evaluated programmes, most programmes under scrutiny are limited to evaluating quite specific skills and competences. Only two studies incorporate a wider scope of DC in their learning materials.

It is noteworthy that new didactical methods opened by introducing ICT-based learning methods seldomly find their way into evaluation studies. Only five of 20 intervention studies explicitly based their intervention format on ICT techniques such as simulation tools, gamification or learning platforms like Moodle (see Table 3). This may be attributed to the predominance of appraisal research in formal educational settings, limited investigations carried out in non-formal educational settings and a complete absence of studies that explore informal interventions outside of the educational system. For example, unobtrusively measuring YouTube education video consumption so far concentrates on patterns of use, and not on the efficacy of information transmission, as Drozd et al. (2018) conclude after a review on 37 studies. Learning processes in self-organised meetings of younger people (e.g., Hackathons, Game Jam, LAN-parties; for an overview see Juraschek et al. 2020) have so far been seldomly evaluated with respect to their efficacy in, for example, skill development of the event participants. Results of studies dealing with event-based learning have been published mainly as conference papers, corresponding to the different *culture* of publishing in the scientific ICT community. Their focus is also often narrow, for example on technical aspects like cybersecurity (Affia et al. 2020), software engineering (Porras et al. 2018) and device-centric authentication to the cloud (Raatikainen et al. 2013). Some authors have asked for the integration of hackathons into formal classes in university courses (e.g., Duhring, 2014; Gama et al. 2018), but this has seldom been realised, nor evaluated so far. Of course, gathering data in informal learning settings is complicated, and rigorous control techniques like randomisation may not be feasible. In institutional contexts there exist methodological alternatives for such situations. For example, from the field of epidemiology stricter study designs producing

better evidence, like case-control studies, calculating propensity scores, and other quasi-experimental designs (see Frick and Rehm, 2016) could be transferred to educational settings.

Regarding the strict institutional approach in formal education contexts predominating the research literature on DC, it is surprising that wide-spread concepts of instruction and education have seldom been used as a theoretical framework. Most prominently, the offer-use model of learning (Vieluf et al. 2020) integrates a process and structure perspective on acquisition of competences (Seidel, 2014). Though developed in the context of schooling in math classes in secondary education, it has shown enough flexibility to be used in creative school subjects (Rakoczy et al. 2022a) and could also easily be transferred to university teaching. By integrating teachers' characteristics, variables covering the learning process and quality (e.g., Rakoczy et al. 2022b), and characteristics of the students (potential, activities, motivation) as determinants of success as measured by multi-criteria instruments, this model seems capable of guiding empirical research on a complex issue like DC.

All in all, it seems that research is bound to institutional access to AYA, and that the target groups and sampling methods are widely determined by the possibilities offered from this enrolment. The strict separation between secondary and tertiary education clearly impedes a more developmental perspective on AYA's DC. Research on higher education students is overrepresented, whereas young people in other educational- or non-educational settings (e.g., in a vocational training program, employed) are not considered. Questions like *'Which early experiences with digital ways of learning, socialising and mindset-forming lead to specific personalities or sovereignty in modern life?'* thus cannot be expected to be answered by the current state of the art in AYA DC research. Most studies treat DC as the outcome of some other factors, which are chosen quite arbitrarily (STUDSPEC representing two thirds of the articles). Except for the historical 'digital divide' topic, no focal points could be found from the analysis of concomitant variables. Though educational science addresses the DC issue with numerous definitions, concepts and research desiderata (e.g., Janssen et al. 2013; Spante et al. 2018), the path to developmental psychology has yet to be trodden. This observation also holds true for evaluated intervention strategies. Perhaps the most noteworthy finding is that research on strategies aimed at fostering AYA's DC still appears to be rather rudimentary.

Limitations

A limitation on the generalisability of the results might be caused by some of the inclusion/exclusion criteria of the literature search. Starting the observation period not earlier than the publication year 2010 could have omitted important arguments for the abandonment of the myth of digital natives. One might speculate that the reason why literature dealing with informal peer-to-peer learning processes is so sparse in our sample is that the scientific discourse on this topic has already been undertaken. Additionally, detecting empirical studies on self-organised learning via their representation in later review articles was not possible due to our decision to exclude reviews. Disregarding the informal acquisition of DC would thus be an artefact. However, a cursory exploration of the connection between informal learning and AYA DC using Google Scholar for the period before 2010 resulted in the conclusion that, of the very sparse literature focusing on DC, most hits could be excluded for other exclusion criteria (especially 'not using quantitative methods' or 'not meeting the age range'). Moreover, papers published before 2010 often dealt with now obsolete internet use (e.g., internet cafés, see for instance Cilesiz, 2009).

The exclusion of conference papers from our analysis prohibited a broader representation of the emphasis that informatics puts on the term 'digital competence'. Academically recognised publications in this field are mainly conference papers. That this different culture of publishing signalises an important constraint when interpreting the research landscape seems questionable. A developmental view and issues of identity formation in younger ages do not play a role for the progress in this discipline. Thus, we might argue that omitting these conference papers does not seriously bias our results. Taking a complementary approach to examining this particular research landscape would be a valuable strategy for a subsequent review methodology.

An important limitation of our survey of the research landscape is obviously our decision to select only quantitative papers. This underestimates the weight of theoretically oriented or qualitative research on AYA DC. Turning this argument to its origin, however, again demonstrates our point that the research issue has not yet reached a phase where a coherent series of evaluation studies could be rolled out in the field. Such a research programme (comparable to clinical trials for a specific disease) might never be adequate for mainly two reasons: First, innovation in human-machine interfaces will most likely evolve in the future, which will require constant redefinitions of necessary DC. Second, the broad meaning of DC covering technical, developmental, psychological and ethical issues will hinder a 'simple' step-by-step programme to close digital deficits in AYA. Overcoming a deficit-oriented approach to fostering DC seems a legitimate goal.

A final limitation pertains to how we defined the denominator for calculating the growth rate of publication statistics. We observed a relatively flat growth rate for DC-related research in AYA. This observation might be skewed because we counted all articles from journals with a broader scope, such as Frontiers in Psychology and Education Sciences (refer to Supplementary Table S5), even if those journals cover more than just human-computer interaction.

Conclusion

Three take-home messages can be drawn from this study: Firstly, a common concept of adolescents and young adults' DC is still being formulated and implemented. Developmental aspects have not yet been integrated into the concept in a satisfactory, theoretically convincing manner. Nor have the various existing frameworks been incorporated into research to a degree that would enable an easy and fruitful comparison of different empirical studies. At the very least, it is nowadays common sense that DC includes much more than merely technical aspects.

Secondly, despite the ongoing emphasis that research and politics lay on the significance of empowering young people to become digital competent and digital sovereign adults, there is a severe lack of systematic assessment on the efficacy of intervention methods for promoting DC. According to our results, there are too few intervention methods that have been quantitatively evaluated for the AYA age group. In addition, the evaluated intervention programmes under review tend to focus on narrow, context-specific digital skills.

The last conclusion derives from a critique of the current state of empirical educational research concerning AYA's DC: Too little attention has been paid to state of-the art concepts (e.g., offer-use-model) in educational science. Balancing and comparing the developmental, cognitive and social needs and demands of adolescents and young adults remains an important desideratum of future research.

Data availability

The authors present the articles used for the study in Supplementary Table S2. The dataset used for the quantitative analyses is provided in Supplementary Table S6.

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Author contributions

AK: Literature search and selection of articles, data management and statistical analysis, data collection of publication trends, substantial analysis of intervention studies, writing - original draft preparation. UF: Conceptualization, supervision of data management and statistical analysis, writing - review and editing. KR: Supervision of developmental issues, substantial interpretation of latent class analyses, writing - review and editing. SJS: Conceptualization, supervision of all study issues (study selection, encoding, analysis, interpretation), writing - review and editing.

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