Assessing digital self-efficacy

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Assessing digital self-efficacy: Review and scale development

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ABSTRACT

Today, digitalization is affecting all areas of life, such as education or work. The competent use of digital systems (esp. information and communication technologies [ICT]) has thus become an essential skill. Despite longstanding research on human-technology interaction and diverse theoretical approaches describing competences for interacting with digital systems, research still offers mixed results regarding the structure of digital competences. Self-efficacy is described as one of the most critical determinants of competent digital system use, and various self-report scales for assessing digital self-efficacy have been suggested. Yet, these scales largely differ in their proposed specificity, structure, validation, and timeliness. The present study aims at providing a systematic overview and comparison of existing measures of digital self-efficacy (DSE) to current theoretical digital competence frameworks. Further, we present a newly developed scale that assesses digital self-efficacy in heterogeneous adult populations, theoretically founded in the DigComp 2.1 and social-cognition theory. The factorial structure of the DSE scale is assessed to investigate multidimensionality. Further, the scale is validated considering the nomological network (actual ICT use, technophobia). Implications for research and practice are discussed.

1. Introduction

The competent use of digital systems has become a critical skill for most areas of life, including education and work. Knowledge and skills regarding digital devices (e.g., computers, smartphones, tablets), applications, and environments have been defined as 21st-century skills as they are essential to participating in education, work, and everyday life in modern societies (OECD, 2016). In recent years, the continuous development of computer hardware and software has steadily improved the capacities of digital systems and rapidly raised the speed of new developments. In particular, with increasing system autonomy, as enabled by artificial intelligence methods, the role of individuals in interaction with these systems is changing (Parker & Grote, 2020). For instance, while specific action steps are eliminated (such as sorting information), digital systems now enable individuals to accomplish increasingly complex tasks or interact with highly personalized systems (Vrontis et al., 2021). Hence, individuals will need to be increasingly digitally competent and adaptable to meet the increased demands and seize the new opportunities that arise (Larson & DeChurch, 2020). The COVID-19 pandemic has accelerated digitalization processes, making the competent interaction with these systems more important than ever.

Research indicates that not only objective skills impact the effective use of digital systems, but also subjective competence beliefs

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(Peiffer et al., 2020). In particular, self-efficacy related to the use of digital systems has been shown to predict the effective use of digital systems (Ulfert et al., 2022). Although related, competences and competence beliefs should be differentiated, as they independently influence learning, motivation, and performance (Hughes et al., 2011; Marsh et al., 2017; Pajares & Schunk, 2002). In the present study, we will specifically highlight the importance of digital self-efficacy (DSE) as a central predictor of successfully completing activities in relation to ICT use (Bandura, 2001; Compeau & Higgins, 1995). A plethora of research shows that competence beliefs, such as DSE (i.e., one's confidence in the successful future use of digital systems), determine whether and how individuals use digital systems (Eastin & LaRose, 2000), or whether they are willing to use it at all (Venkatesh & Bala, 2008). Due to its central role in interacting with digital technologies, DSE has been described as a "building block" of digital competences (Janssen et al., 2013, p. 478).

Various terminologies are used in the literature to describe objective competences for using digital systems (e.g., information and communication technology [ICT] skills, computer literacy, digital competencies; Jin et al., 2020) and different theoretical frameworks have been suggested. The majority of these frameworks focus on the retrieval and processing of information and content production using digital systems (see e.g., Jin et al., 2020; Siddiq et al., 2016). Yet, scholars have argued that digital competence frameworks should also include aspects relating to safety and problem-solving (Calvani et al., 2012; Carretero et al., 2017). Due to the variety of terminologies and frameworks addressing the competent use of digital systems, there are continuing debates about defining and measuring digital competences as well as the construct's structure. While most frameworks define digital competences as multi-dimensionally structured (e.g., Carretero et al., 2017; Ferrari, 2013), many measures assess only a single competence score (Jin et al., 2020). Thus far, the European Commission has proposed one of the most integrative frameworks of digital competences for citizens, which has also been extended to educational and work contexts (see, e.g., DigComp 2.1.; Carretero et al., 2017). According to publications by the European commission (Directorate-General for Education, 2019, p.12), digital competence is defined as "the confident, critical and responsible use of, and engagement with, digital technologies for learning, at work, and for participation in society". It encompasses a combination of knowledge, that is having an understanding relating to how digital systems may be used, how they function, and how to judge their capabilities and restrictions, skills: "to use, access, filter, evaluate, create, program, and share digital content", as well as to "protect, information, content, and digital identities" (p.10), and attitudes, including the reflective and critical handling of these systems. Similar definitions have been used in the multiple versions of the digital competence framework Digcomp (Carretero et al., 2017; Ferrari, 2013; Vuorikari et al., 2016, 2022) and many research studies in the digital competence domain (see e.g., Mattar et al., 2022). Based on this definition, the DigComp (e.g., Carretero et al., 2017; Vuorikari et al., 2022) suggest five dimensions of digital competences: Information and data literacy, communication and collaboration, digital content creation, safety, and problem solving.

Although these digital competence frameworks are well established in the literature and while the importance of DSE for interacting with digital systems has been confirmed in many empirical studies (e.g., relating to computer use), measures of DSE thus far rarely refer to this field of literature. As a consequence, most measures of DSE are focused on measuring self-efficacy as a unidimensional construct, for instance with regards to the general use of computers, the internet (e.g., Compeau & Higgins, 1995; Eastin & LaRose, 2000), or specific software applications (e.g., Davis & Tuttle, 2013). This is in stark contrast to current considerations in the digital competence literature, which suggests a multidimensional structure of digital competences. Further, current measures of DSE often disregard central aspects proposed by digital competence frameworks, such as safety and problem-solving (Carretero et al., 2017).

The aim of the present study is threefold: First, we aim to provide an overview and compare existing approaches for measuring individuals' DSE in a scoping review. Second, we compare these measures to existing models of digital competences and will highlight the need for new scale development. Lastly, we will newly validate an economical scale that describes the structure of DSE as defined by multidimensional frameworks of digital competences, particularly focusing on the differentiation of tasks and domains (e.g., problem-solving).

2. Background

2.1. Structure of digital competence

Various terminologies (e.g., ICT literacy, ICT skills, media competence, etc.) are used to describe digital competences, with most terms being focused on ICT use (Jin et al., 2020; Oberländer et al., 2020). Ferrari et al. (2014) argue that digital literacy needs to be differentiated from competences. They describe literacy as a precondition of digital competences, that is, the skills required to achieve competence. Thus, digital literacy "comprises of basic ICT skills, which lead to digital competence" (Ferrari et al., 2014, p. 9). Further, it has been argued that "digital competence goes beyond the digital literacy skill" and "include an important focus on attitudes and mindset" (Jin et al., 2020, p. 2). Several skills have been suggested to form these central prerequisites. They include general skills (e.g., general cognitive skills), skills related to the use of digital systems (e.g., basic computer skills), as well as personality variables such as attitudes (Peiffer et al., 2020). In recent years, many review studies have investigated the differentiation of digital literacy and competences as well as digital competence frameworks across application domains (for an overview see e.g., Oberländer et al., 2020; Zhao et al., 2021). Yet, although there are similarities in definitions, digital competences are generally considered to go beyond mere literacy by considering skills, knowledge, and attitudes (Ala-Mutka, 2011; He & Li, 2019; Oberländer et al., 2020). Comparative studies further highlight similarities between different digital competences framework, specifically in their suggested competence areas, such as communication and collaboration or privacy and security (which are e.g., included in DigComp, Janssen et al., 2013; Oberländer et al., 2020) or problem solving (e.g., included in DigComp, Calvani et al., 2012; Janssen et al., 2013). At the same time, recent reviews suggest that the DigComp is one of the most widely used frameworks for describing digital competences (Zhao et al., 2021). Therefore, we will further focus on the competence areas suggested in the DigComp.

The European Digital Competence Framework for Citizens (Carretero et al., 2017; Ferrari, 2013; Ferrari et al., 2014; Vuorikari et al., 2022) identifies five competence areas, consisting of a total of 21 competences, underpinning digital competences (see Table 1). Next to differentiating knowledge, skills, and attitudes, the framework further suggests different proficiency levels (e.g., foundation, intermediate, advanced) that range from the simple application of software to creating new solutions to problems by utilizing digital technologies (Carretero et al., 2017). The DigComp has been used in research and practice alike and has been tested with regard to its applicability across different geographical regions (Law et al., 2018).

Although theoretical frameworks of digital competences, like DigComp, point towards a multidimensional construct, empirical studies report mixed results and often refer to a unidimensional structure (Jin et al., 2020; Peiffer et al., 2020). For example, large international digital literacy assessments, such as the ICILS or the PIAAC assessment, only describe a one-dimensional scale for measurement (Fraillon et al., 2019; OECD, 2016). Yet, some studies have reported a better fit of multidimensional models to the data compared to unidimensional models (Rubach & Lazarides, 2021; Siddiq et al., 2017). These heterogeneous results have been attributed to high correlations among the different competence areas (Ihme et al., 2017; Wilson et al., 2017), suggesting a need for further investigation of the structure and the development of measures of digital competences that include all competence areas identified in the DigComp framework (Jin et al., 2020; Lucas et al., 2022; Peiffer et al., 2020). This includes the competence area of problem-solving, which current measures of digital competences mainly address as solving technical problems. In contrast, the DigComp highlights the skill of being able to utilize digital systems for solving a variety of problems, not being limited to technical error. Recent works have further highlighted the need for including these different types of problem-solving, that are described in DigComp2.1, rather than only highlighting competences to solve technical errors (Rubach & Lazarides, 2021). Additionally, according to DigComp, problem-solving also includes the aspect of being aware of one's own competences, and detecting competences gaps. Furthermore, competently dealing with risks and safety concerns online has become an increasing concern for all age groups (Janssen et al., 2013; Livingstone et al., 2011). These aspects have thus far been largely omitted in most approaches, but will play an increasingly important role as all areas of life are being highly digitalized (Elstad & Christophersen, 2017). Recently, first approaches have been suggested that encompass measures of digital competences along the competence areas suggested by the DigComp (e.g., Clifford et al., 2020; Lucas et al., 2022). Yet, while these measures relate to digital competences, they do not represent measures of self-efficacy (see Marsh et al., 2017 for an overview of how self-efficacy measures differ from related competence beliefs and competence measures).

2.2. Developing digital competences: the role of digital self-efficacy

Mental representations of one's performance, competences, and abilities, such as self-efficacy, can significantly influence the development of digital competences (Peiffer et al., 2020). Previous research highlights the central role of self-efficacy for motivation in diverse performance contexts, such as work or education (Eccles & Wigfield, 2002). The concept was initially introduced as part of social cognitive theory by Bandura (Bandura, 1977) and is defined as an individual's confidence to successfully perform a specific task (Bandura, 1997, 2001). As such, self-efficacy refers to cognitive, goal-referenced beliefs which are future-oriented judgment and are relatively context specific (Bong & Skaalvik, 2003; Marsh et al., 2017; Schunk & Pajares, 2007). In social cognitive theory self-efficacy

Table 1
Competences defined in DigComp 2.1

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

Source: Carretero, Vuorikari, and Punie (2017).

is closely tied to an individual's performance (Saleh, 2008). Although self-efficacy is related to an individual's competences, they need to be differentiated, as individuals may over- or underestimate their competences, influencing subsequent learning and behavior (Pajares & Miller, 1994; Pajares & Schunk, 2002).

Especially in the context of acquiring new skills, previous research showed that self-efficacy is an important predictor of learning outcomes (Kapucu & Bahçivan, 2015; Liou & Kuo, 2014). Further, it has been argued that knowledge creation is determined by one's belief in one's ability to successfully perform a task (Ale et al., 2017; Schunk & Pajares, 2007). Specific to the context of digital competences, empirical studies have shown ICT self-efficacy to be a central predictor of digital competences and subsequent use of digital systems (Hatlevik, 2017; Hatlevik et al., 2018). Similarly, it has been suggested that computer self-efficacy impacts a person's acceptance of new ICTs and may either foster or hinder the development of effective skills for interacting with digital systems (Ertmer et al., 1994; Hatlevik et al., 2018; Wartella & Jennings, 2000). Relatedly, internet self-efficacy has been shown to predict performance in online exams (Joo et al., 2000) and learning motivation and performance (Chang et al., 2014). Individuals who negatively perceive their ability to successfully perform a task in a digital environment (low DSE) will be less willing and likely to use such a system, even if their digital competence is high (Hsia et al., 2014). Thus, DSE is not only positively related to learning and developing new skills, such as digital competences, but will also impact individual's willingness to use digital systems (Hsu & Chiu, 2004; Joo et al., 2018; Kher et al., 2013). The frequent use of digital systems may further increase DSE and thus enable more effective use of these systems (Eastin & LaRose, 2000). Overall, DSE does not only reflect an individual's perception of their ability but can also form a critical influence on future behavior (Marakas et al., 1998). As such, DSE plays a central role in interacting with digital technologies that is distinct from digital competences.

2.3. Measurement of digital self-efficacy

Different approaches have been suggested to measure self-efficacy, with either specific task, domain, or a more general focus (Chen et al., 2001; Marsh et al., 2017). Social cognitive theory suggests that self-efficacy should be measured focusing on a specific domain or task and should reflect a judgment of one's capability (Bandura, 2006). Further, research suggests that measures of self-efficacy should not invoke social comparison, for instance by providing a criterion for successful performance (Marsh et al., 2017). Concerning the use of digital systems, a variety of measures of DSE have been used, such as computer, internet, ICT, or task-, feature-, and software-specific self-efficacy (e.g., DSE related to the use of a specific learning program; Briz-Ponce et al., 2017).

One of the earliest and most prevailing DSE instruments has been computer self-efficacy (Weigel & Hazen, 2014). It has been suggested that computer-self efficacy can be measured at both a general and a specific level (Bao et al., 2013; Marakas et al., 1998). Most scales for measuring computer self-efficacy (Compeau & Higgins, 1995) have a general focus on the "individual's judgment of efficacy across multiple computer application domains" Marakas et al., 1998, p. 129). In contrast, specific computer self-efficacy will focus on an individual's judgment with regard to a specific task while using a computer (Marakas et al., 1998). Specific self-efficacy may contribute to the formation of general self-efficacy (Gist & Mitchell, 1992) but cannot be treated interchangeably, as they are distinct theoretical constructs (Marakas et al., 1998). However, literature on computer self-efficacy has often disregarded this differentiation, and definitions and scales are used interchangeably (Weigel & Hazen, 2014). Additionally, computer self-efficacy scales have been criticized for neglecting the dynamic nature of digital systems, leading to items becoming outdated after some time (Weigel & Hazen, 2014). For example, early measures of computer self-efficacy refer to monochrome monitors, floppy discs, or DOS, which many of today's computer users will be unfamiliar with. With technology development and change becoming increasingly rapid, merely changing the wording may not be sufficient (Jarvis et al., 2003).

With increasing importance of the internet for everyday life, new DSE measures were needed and developed, particularly focusing on internet use (Torkzadeh & Van Dyke, 2002). Inspired by measures of computer self-efficacy (Compeau & Higgins, 1995), internet self-efficacy is usually a general measure of one's judgment of confidence with regards to different tasks related to internet use (e.g., troubleshooting or joining an online discussion group; (Eastin & LaRose, 2000). More recently, self-efficacy scales focused on ICT use have been suggested. These scales are comprised of both computer and internet self-efficacy (Aesaert et al., 2017; Rohatgi et al., 2016). Furthermore, many ICT self-efficacy scales are closely related to important skills indicated by ICT frameworks (e.g., ICILS; Fraillon et al., 2014) such as digital information processing or communication (Aesaert & van Braak, 2014; Hatlevik et al., 2018) and more advanced skills, such as programming (Rohatgi et al., 2016). Although newer measures, such as ICT self-efficacy, consider multiple digital competences indicated in the DigComp, the measures are usually reported as a unidimensional construct or focus on specific application domains or groups of individuals rather than competence domains (e.g., using ICTs for school, work, or leisure).

Today, technological development is happening with growing speed and changes individuals' interaction with digital systems in various ways (Ulfert et al., 2022). For example, to use the internet for different types of activities (e.g., information search or content creation), users do not need to be proficient in a specific device any longer but may use different devices (e.g., desktop computers, smartphones, tablets). Similarly, over recent years, user interaction has been fundamentally transformed. For example, software applications now come with a much larger variety of functions (e.g., a learning software extended by new adaptive functions) and for users to perform actions they now interact quite differently with these systems (e.g., discussing political opinions on online forums vs. social media). As technological development continues, this is likely to change further.

Current measures of DSE show limitations in various ways. First, they often do not consider more recent frameworks of digital competences, such as the DigComp regarding their level of generality, the competences included, and their multidimensionality. The DigComp describes digital competences in terms of general actions (i.e., tasks, functions), such as protecting devices or managing data, that can be applied to a heterogenous group of individuals and are independent of specific digital systems. Most DSE scales are still system (e.g., specific computer software) or technology-specific (e.g., data storage such as floppy disc) and may thus become outdated.

Further, critical competence areas, such as safety and problem-solving are often disregarded. Additionally, the literature shows inconsistencies regarding the structure of the construct as the majority of current DSE scales do not regard a multidimensional structure as suggested by prominent digital competence frameworks.

Second, the term DSE has been used interchangeably for measuring general competence beliefs (i.e., including items assessing self-concept, another competence belief) or actual proficiency. As a result, this has led to inconsistencies in the representation of the DSE construct in the literature. This is in spite of self-efficacy literature offering clear definitions of how measures should be constructed and its well-defined differentiation from related constructs, such as self-concept (Bandura, 2006; Marsh et al., 2017; Pajares & Schunk, 2002).

Lastly, measures of DSE are most common in the educational context, focusing for example on students' or teachers' interaction with digital learning material (see e.g., (Nordén et al., 2017; Rubach & Lazarides, 2021; Siiman et al., 2016). Thus, generalizability of these findings to other populations, such as employees, is restricted.

Consequently, new DSE measures are needed to consider the multidimensional structure of digital competences without focusing on a specific application that, with the current pace of technological development, might be at risk of becoming outdated too fast. Furthermore, a DSE measure focused on actions rather than specific devices may be used to study the status of DSE in the population and its development over time.

3. Scoping review

3.1. Method

A scoping review (PRISMA) was conducted to provide a comprehensive overview of current self-efficacy measures relating to the use of digital systems. The aim of the review was to explore existing measures of self-efficacy that relate to the use of digital systems and to identify their theoretical foundation. Specifically, the aim was to investigate for which target groups measures exist and whether existing scales consider an uni- or multidimensional structure of the construct.

3.1.1. Search strategy

The first search was conducted in April 2021 on PsychINFO and PsychArticles. A second search was conducted in June 2022 on ERIC database. Both searches were restricted to abstracts, titles, and key words of peer-reviewed sources published between 2000 and 2021. To account for the multiple variations of digital environments and systems, the following keywords were concatenated with Boolean "OR" operators: digital, technology, computer, internet, and ICT. Several alternative keywords were tested (e.g., information technology, DigComp) but did not yield any relevant references that were not already generated with the aforementioned search term. The final search term was: (digital OR technology OR computer OR internet OR ICT) AND (self-efficacy).[2] In PsycINFO, we used the 'Tests and Measures' field to focus only on measures of self-efficacy. This function utilizes the database PsycTESTS,[3] which comprises psychological tests and measures by the APA designed for use in social and behavioral science research. In ERIC we utilized the 'Tests/Questionnaires' option to narrow down results.

3.1.2. Selection process

In total, the search generated $N = 485$ sources. Four duplicates were removed from the raw list of literature entries, with 481 sources remaining for further inspection. In the next steps, a study was to be included in case it met the following selection criteria:

1. The article's full text had to be available in English or German.
2. The source included a measure of self-efficacy.
3. Self-efficacy was measured regarding the use of a digital systems (e.g., internet, computer, web applications, etc.)
4. In the final step, we only included sources that developed a digital self-efficacy measure. Scale development and validation had to be described as part of the paper.

At each step, reviewers rated whether a source clearly fulfills the criteria or in whether they need to be discussed. First, two independent reviewers scanned the sources by titles and abstracts. At this stage, there was a full overlap between reviewer ratings. $N = 225$ sources were excluded, as they were unrelated to the query (see Fig. 1). Next, the remaining sources were evaluated in full text according to the criteria for inclusion. At this stage, $n = 35$ cases were further discussed amongst the reviewers with regards to the exclusion criteria (e.g., checking again whether information on the scale development process were indeed not provided). On the basis of the described content-based criteria, a total of $n = 243$ documents were excluded. Among the reasons for excluding a paper, sources using measures developed in prior studies or minor adaptations were the most common reason ($n = 181$). Few other studies only measured academic or general self-efficacy or were unrelated to self-efficacy ($n = 32$). The final sample consisted of $n = 17$ sources included in the literature review.

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[2] Sample search term (ERIC), including the indicated restrictions: ((digital or technology or computer or internet or ICT) and self-efficacy).mp. [mp = abstract, title, heading word, identifiers] limit 1 to (journal articles and peer reviewed and yr = "2000–2021″ and "tests/questionnaires").

[3] See https://www.apa.org/pubs/databases/psyctests/index?_ga=2.123048395.1910903677.1631269901-354292183.1631269901.

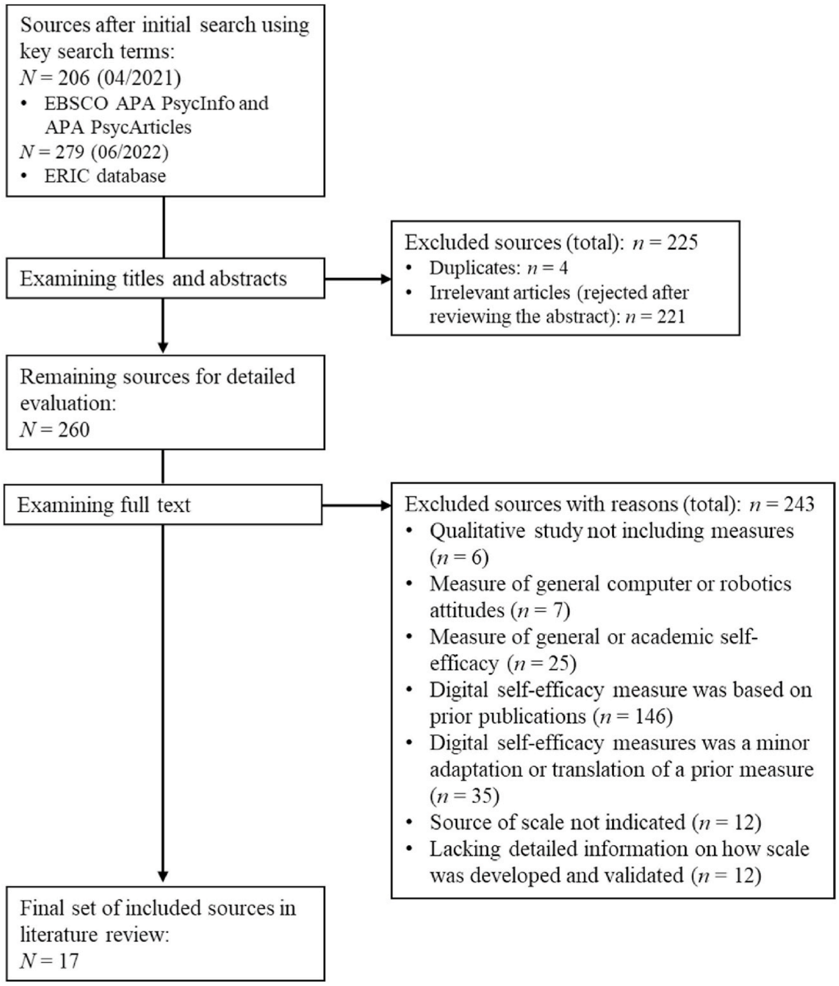

Fig. 1. PRISMA chart.

3.2. *Results*

The final list of sources encompassed self-efficacy scales concerning computers, the internet, computer programming, technology, gaming, ICT, and healthcare technologies (see Table 2). The scales were further analyzed regarding the context of the study, the scales' generality level, dimensionality, and theoretical foundation. Most studies were set in an academic context, focusing on pupils, university students or pre-service teachers. All but two studies (Hong et al., 2013; Rafiee & Abbasian-Naghneh, 2021) developed general DSE scales, focused on various tasks or situations within a given domain (e.g., as part of computer use). Six studies suggested a multidimensional structure for internet (Kao et al., 2014; Kim & Glassman, 2013; Yasan Ak, 2020), ICT (Kiili et al., 2016; Tzafilkou et al., 2021), and computer programming self-efficacy (Tsai et al., 2019). All other studies reported a unidimensional structure of the self-efficacy measure. Concerning theoretical foundations of the scales, most studies were based on prior literature on self-efficacy and previous DSE scales, or research relating to the domain addressed in the scale (e.g., computer programming competences). Two scales did not report on the theoretical basis of the developed scale in detail (Chung & Nam, 2007; Hatlevik et al., 2015).

In addition to the scales included in the final set of sources of the literature review, many of the sources excluded at step 4 referred to or adapted previously existing scales. The majority of scales cited in these articles were not included in our search as they were published prior to 2000. These findings are in line with prior suggestions that most DSE scales are adaptations of prior scales (Weigel & Hazen, 2014). For an overview of the adapted scales, please see appendix A1.

3.3. *Discussion of systematic review*

In sum, the literature review of existing DSE scales confirmed that, to date, most DSE scales are general measures of DSE of specific contexts of use (e.g., Healthcare technologies; Rahman et al., 2016). The theoretical foundation of the scales included in this review were usually based on self-efficacy theories, prior DSE scale (e.g., computer self-efficacy), and research from the human-computer

Table 2
Papers and studies included in the review.

Self-efficacy	Paper/Study	Context	Generality	Dimensionality	Based on
Computer	Cassidy and Eachus (2002)	Undergraduate students	General	Unidimensional	Previous scales of computer self-efficacy (Busch, 1995, p. 199; Compeau & Higgins, 1995; Hill et al., 1987b; Kinzie & Delcourt, 1991; Miura, 1987; Murphy et al., 1989; Torkzadeh & Koufteros, 1994) and self-efficacy theory (Bandura, 1986)
	Porto Bellini et al. (2016)	Undergraduate students	General	Unidimensional	Previous self-efficacy, computer anxiety, or computer self-efficacy theories and measures (Bandura, 1997; Chen et al., 2001; Conrad & Munro, 2008; Hill, Smith, & Mann, 1987a; Hsu & Chiu, 2004; Hsu & Huang, 2006; Igbaria & Iivari, 1995; Korobili et al., 2010; Marakas et al., 2007; Ortiz de Guinea & Webster, 2011; Sang et al., 2010; Smith et al., 2007; Torkzadeh & Van Dyke, 2002)
	Stephens (2006)	Computer use in business	General	Unidimensional	Previous measures of computer self-efficacy (Murphy et al., 1989) and self-efficacy theory (Bandura, 1977)
Internet	Chung and Nam (2007)	University student's instant messenger use	General	Unidimensional	Self-developed six-item measure; No specific theory indicated for item development
	Kao et al. (2014)	Teacher web-based professional development	General	Multidimensional (3-factor model)	Prior internet self-efficacy scales (Kao & Tsai, 2009) and self-efficacy theory (Bandura, 2006)
	Kim and Glassman (2013)	University students	General	Multidimensional (5-factor model)	Previous computer and self-efficacy measures and literature on internet use (Castells, 2007; Compeau & Higgins, 1995; Eastin & LaRose, 2000; Glassman & Kang, 2012; Miltiadou & Yu, 2000)
	Rafiee and Abbasian-Naghneh (2021)	Online communication in e-learning	Specific	Unidimensional	Prior publication on online learning readiness (Yurdugül & Alsancak Sarikaya, 2013). No theoretical foundation in self-efficacy theories.
	Yasan Ak (2020)	Internet literacy in pre-service teachers	General	Multidimensional (4-factor model)	Literature on internet literacy and technology self-efficacy (Kao et al., 2011; Kim & Glassman, 2013; Lee et al., 2015; Livingstone et al., 2005; Serap Kurbanoglu, 2003; Tella, 2011)
	Zimmerman and Kulikowich (2016)	Online learning	General	Unidimensional	Prior scales of online learning self-efficacy (DeTure, 2004; Miltiadou & Yu, 2000) and self-efficacy theory (Bandura, 1986, pp. 197, 1997)
Technology	Hopp and Gangadharbatla (2016)	Technology adoption in university students	General	Unidimensional	Literature on internet and computer self-efficacy (Eastin & LaRose, 2000; LaRose & Eastin, 2004; Larose et al., 2001; Simmering et al., 2009)
Programming	Tsai et al. (2019)	Students	General	Multidimensional (5-factor model)	Conceptual framework of distributed computational thinking (Berland & Lee, 2011)
Gaming	Hong et al. (2013)	Using games for increasing motivation for visiting museums in students	Specific	Unidimensional	Based on theories and measures of self-efficacy (Bandura, 1997; Riggs & Knight, 1994)
ICT	Aesaert et al. (2015)	Student ICT use	General	Unidimensional	21st century competences (Voogt & Roblin, 2012)
	Hatlevik et al. (2015)	Student digital competences	General	Unidimensional	Self-developed three-item measure. No specific theory indicated for item development
	Kiili et al. (2016)	Computer[a] and Technology integration in pre-service teachers	General	Multidimensional (two dimensions of construct refer to ICT self-efficacy)	Based on constructs of teacher self-efficacy (Bandura, 1997), computer self-efficacy (Compeau & Higgins, 1995), and self-efficacy towards technology integration (Wang et al., 2004)
	Tzafilkou et al. (2021)	ICT teaching and ICT transfer of training	General	Multidimensional (two dimensions of construct refer to self-efficacy)	Based on transfer of training questionnaires (e.g. Judge & Bono, 2001; Kim & Kim, 2003; Lee, Lee, Lee, & Park, 2014; Liebermann & Hoffmann, 2008)
Healthcare technologies	Rahman et al. (2016)	Attitudes about healthcare technologies	General	Unidimensional	Different theories in the domain of using healthcare technologies (Anderson & Agarwal, 2010; Durndell & Haag, 2002; Holcomb et al., 2004; Johnston & Warkentin, 2010; Lee & Larsen, 2009; Sun et al., 2013; Tsang et al., 2013)

[a] Although the scale is labeled as computer self-efficacy, all items refer to the use of ICT.

interaction domain. The majority of scales have been developed for specific contexts or groups, especially in the educational domain. In our review of the literature, we found that DSE scales were primarily targeted at high school and university students and were often device- (i.e., hardware-specific; computer, smartphone, Tablet) or software-specific (word, excel) rather than function-specific (e.g., content creation). Further, scales did not differentiate between different dimensions suggested in the DigComp but often assessed DSE as a unidimensional construct. Lastly, the majority of scales focused on only three aspects that are part of the DigComp2.1. competence areas (i.e., information and data literacy; communication and collaboration, and problem-solving aspects) rather than including all five competence areas.

Therefore, developing a new type of DSE scale is relevant for several reasons. First, there is a need for a scale that is based on an integrative theoretical framework of digital competences, such as the DigComp 2.1, that represents the multidimensional nature of the construct. Second, only few scales consider the fact that items that are focused on specific digital systems or environments may become outdated. Thus, a new scale should be independent of a specific system. Third, there is a need for a DSE scale that applies to diverse contexts outside of academic settings and to diverse age groups in an economical manner. This will also enable researchers to use the scale in large-scale assessments. Fourth, especially with regard to the competence area of problem-solving, it became clear that problem-solving is often only referred to as solving technical difficulties (e.g., experiencing computer malfunctions). In contrast, the DigComp 2.1. also includes the competence of solving problems by utilizing the functions of digital systems and developing new solutions. The skill of using ICTs for solving problems has been argued to become increasingly important as all areas of life are becoming increasingly digitalized, thus becoming a core future skill (Elstad & Christophersen, 2017). Lastly, none of the scales included the dimension “safety” which is included in DigComp as a dimension of a multidimensional ICT concept.

Based on the findings of the systematic scoping review, we developed and validated a new German-language DSE scale designed for the use in heterogeneous populations, and based on the multidimensional structure of digital competences, as suggested by DigComp2.1

4. Scale development

4.1. Method

4.1.1. Item generation

The concept that underlies the developed scale is logically and theoretically derived from Bandura’s (Bandura, 1977, 1986, 1997) concept of self-efficacy and the theoretical framework that describes the structure and content of digital competences, the DigComp 2.1 (Carretero et al., 2017). Thus, we define DSE as “an individual’s perception of efficacy in performing tasks related to the use of digital system”. Thereby, DSE is not just a subjective assessment of skills, but reflects a dynamic composite of multiple factors, including perceived ability and motivational and adaptation aspects (Gist & Mitchell, 1992; Wood et al., 2014).

The newly constructed items of this scale were developed by the authors of this paper, who are subject matter experts in the field of self-efficacy, self-concept, psychological assessment, and human-technology interaction research. In a first step, items for all competence areas defined in the DigComp 2.1. were constructed independently by the two authors. In a second step, the two researchers compared these items regarding similarity and wording in iterative discussion rounds.

We generated new items (see Appendix, Table A3) to capture self-efficacy related to the five dimensions (competence areas) 1: information and data literacy (iSE), 2: communication and collaboration (cSE), 3: digital content creation (dSE), 4: safety (sSE), and 5: problem-solving (pSE). DigComp includes eight proficiency levels for each of the 21 competences. Items were numbered in accordance with the DigComp competence area (dimension 1). The second number presents the single competences (dimension 2). When the detailed descriptions of the single competence area (Carretero et al., 2017, p. 23ff) included multiple aspects, we formulated at least two items for the competence. Thus, in cases where a single competence could not be represented in one item, we choose “a” and “b” to indicate this. To construct items that are valid regardless of a participants’ ability level and to avoid social comparison (as suggested by Marsh et al., 2017), no references to the specific proficiency levels were included.

Moreover, we aligned the dimension of problem-solving with the concept of *problem-solving in technology-intensive environments* developed and used in the OECD PIAAC study. In PIAAC, problem-solving “focuses on the abilities to solve problems for personal, work and civic purposes by setting up appropriate goals and plans, and accessing and making use of information through computers and computer networks” (OECD, 2012).

When choosing the wording of the items, we took care that we used the wording for the items to match the suggestions by Bandura (2006) for assessing self-efficacy. Expressions such as “I am confident” and “I will” were used to capture the prospective nature of self-efficacy.

4.1.2. Pretests/cog lab

In a cognitive pretest ($N = 11$) conducted in a CASI in June 2020 with individuals of different age groups and professions (subject-matter experts, undergraduate and graduate students in psychology and sociology, employees; recruited by the authors), we tested the understanding of the newly developed items. Participants were asked to describe what they precisely understood by each item and describe examples of the situation or task. The descriptions were then compared with the mentioned situations and tasks in the DigComp 2.1. Results indicated that, on average, the items were understood according to their intended meaning. This supports face validity (Johnson, 2013) which is particularly important to ensure, as the item formulations are on a high level of generality and universality and are thus very abstract. Furthermore, we ensured content validity by also including subject matter experts in the pretesting.

4.2. Study

4.2.1. Sample

The validation study of the DSE scale was conducted in August 2020 in a web-based survey (CASI) with a quota sample[4] ($N = 627$) in Germany by the survey provider Respondi AG. We assessed a set of sociodemographic variables (gender, age, highest level of education, income, and employment status) and further constructs and variables to validate the scale. Data from the German Census (2011) were used as a reference.[5] To avoid bias introduced by a lack of reading or language proficiency, we recruited only native speakers. Further, respondents who completed the full questionnaire —that is, who did not abort the survey prematurely—were included in the sample. Participants were financially rewarded for their participation.

The study was administered in a 3-form planned missing design (Graham et al., 1994). Variables and items (i.e., survey questions) were divided into four subsets including a common block (X) and three partial blocks (A, B, and C). Items in the X set are administered to every participant (i.e., demographics, frequency of ICT use, items of the DSE scale). The item sets in the three forms A, B, and C are rotated so that different item sets appear in each form. As a result, one-third of the participants do not answer the questions in sets A, B, and C (i.e., validation measures).

Before running the analyses, we screened the data for potentially invalid cases. Cases were excluded based on (a) ipsativized variance - i.e., the variance within an individual across items (Kemper & Menold, 2014) -if the individual fell into the bottom 5% of the sampling distribution of ipsativized variance; (b) the Mahalanobis distance of a person's response vector from the average sample response vector (Meade & Craig, 2012) -if the person fell in the top 2.5% of the sample distribution of Mahalanobis distance; (c) implausibly short response times, namely, if the person took less than 1 s on average to respond to an item. All exclusion criteria were applied simultaneously. Any respondent who violated one or more of the three criteria was excluded from the analyses, and only those who met all three criteria were included. The final sample consisted of $N = 571$ participants. The demographic characteristics of the study participants are shown in Table A2.

To be able to assess test-retest reliability, we presented the same items to a subsample of $n = 147$ participants approximately 6 weeks later. Thereby, care was taken to preserve that the quota of the main survey was maintained. After excluding invalid cases (see screening of the main survey), the final pretest sample consisted of $n = 137$.

4.2.2. Measures

4.2.2.1. Validation constructs/variables.

Technophobia was measured with three items from the subscale "Computer Anxiety Scale (COMA)" of the Incobi-R measurement instrument by (Richter et al., 2010). The items were adapted from the wording to the general use of digital systems (i.e., ICT; e.g., " When working with digital systems, I am often afraid of breaking something."). The response format consisted of a 6-point Likert scale from 1 = strongly disagree to 6 = strongly agree. Reliability, calculated via McDonald's Omega, was good at $\Omega = 0.84$.

Frequency of use of digital systems was captured with five items from the OECD PIAAC study (see Rammstedt, 2013). One item each to capture the frequency of use related to using a programming language, spreadsheet programs, word processing programs, researching on the Internet, online payment systems, and communicating via the Internet. The response format consisted of five categories (1 = never, 2 = less frequently than once a month, 3 = less frequently than once a week but at least once a month, 4 = at least once a week but not daily, 5 = daily).

Internal locus of control and external locus of control was assessed with two items per dimension with the "Internal-External Locus of Control-4″ scale (Kovaleva et al., 2014). The response format consisted of a 6-point Likert scale ranging from 1 = strongly disagree to 6 = strongly agree. Reliability, calculated via McDonald's Omega, was good at $\Omega = 0.80$ for *Internal locus of control* and acceptable for *external locus of control* ($\Omega = 0.55$).

Big Five Personality. We assessed emotional instability with the three-item facet of the BFI-2-XS (Rammstedt et al., 2018). Reliability estimated via McDonald's Omega was acceptable ($\omega = .68$). We inverted on item, so that higher values correspond to higher representation of the respective construct. Respondents rated the items on a five-point Likert scale from 1 = disagree strongly to 5 = agree strongly.

4.2.3. Analyses

We ran all analyses with Mplus (Muthén & Muthén, 1997–2017) version 8.6 within structural equation modeling using a robust maximum likelihood estimator (MLR) as the estimator for the models to account for non-normally distributed data (e.g., (Enders, 2010). To handle missing values, we used the full information maximum likelihood estimator (FIML), which leads to unbiased parameter estimates when at least the "missing at random" (MAR) condition for missing data is fulfilled (Enders, 2010). Due to a three-form planned missingness design of the study (see, e.g., Graham, 2012), missing values are "missing by design," and therefore, the "missing completely at random" (MCAR) condition is met, which is an even stricter assumption (Enders, 2010). Covariance coverage ranged from 66,4% to 100%.

To evaluate the model fit of the single models, we used the rules of thumb proposed by Hu and Bentler (1999) and Browne and

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[4] ZENSUS 2011.

[5] https://ergebnisse.zensus2011.de/?locale=en.

Table 3

Descriptive statistics (N, SD) and Zero-order inter-item correlations of DSE scale items.

	DSE11	DSE12	DSE13	DSE21	DSE22	DSE23A	DSE23B	DSE24	DSE25	DSE26A	DSE26B
DSE11	1.000										
DSE12	0.717	1.000									
DSE13	0.765	0.679	1.000								
DSE21	0.748	0.677	0.774	1.000							
DSE22	0.761	0.645	0.764	0.840	1.000						
DSE23A	0.624	0.598	0.641	0.729	0.726	1.000					
DSE23B	0.518	0.608	0.588	0.603	0.631	0.669	1.000				
DSE24	0.719	0.692	0.713	0.766	0.769	0.730	0.717	1.000			
DSE25	0.724	0.694	0.764	0.769	0.759	0.684	0.648	0.818	1.000		
DSE26A	0.505	0.553	0.585	0.586	0.596	0.602	0.631	0.606	0.600	1.000	
DSE26B	0.630	0.652	0.679	0.691	0.683	0.679	0.669	0.716	0.725	0.715	1.000
DSE31	0.626	0.681	0.680	0.696	0.701	0.699	0.668	0.760	0.743	0.680	0.774
DSE32	0.552	0.647	0.622	0.636	0.643	0.661	0.659	0.692	0.669	0.676	0.732
DSE33	0.538	0.571	0.553	0.557	0.576	0.563	0.584	0.566	0.566	0.602	0.601
DSE34	0.254	0.379	0.306	0.330	0.324	0.370	0.364	0.341	0.283	0.419	0.364
DSE41	0.430	0.514	0.478	0.512	0.521	0.465	0.551	0.488	0.487	0.591	0.542
DSE42	0.469	0.529	0.503	0.532	0.564	0.486	0.584	0.560	0.524	0.607	0.567
DSE43A	0.473	0.578	0.508	0.516	0.532	0.493	0.561	0.522	0.520	0.568	0.552
DSE43B	0.479	0.549	0.498	0.533	0.514	0.505	0.543	0.501	0.507	0.543	0.576
DSE44	0.478	0.551	0.515	0.532	0.520	0.508	0.574	0.537	0.537	0.569	0.566
DSE51A	0.483	0.578	0.542	0.571	0.580	0.544	0.598	0.565	0.572	0.610	0.595
DSE51B	0.426	0.497	0.481	0.525	0.505	0.530	0.535	0.518	0.488	0.607	0.561
DSE52	0.429	0.540	0.507	0.542	0.514	0.542	0.589	0.564	0.511	0.623	0.575
DSE53	0.293	0.436	0.365	0.378	0.361	0.427	0.495	0.396	0.360	0.555	0.451
DSE54	0.456	0.514	0.487	0.532	0.518	0.502	0.521	0.491	0.506	0.554	0.549
M	4.50	4.22	4.51	4.38	4.42	4.09	4.08	4.33	4.41	3.95	4.18
SD	1.07	1.19	1.26	1.28	1.25	1.31	1.30	1.26	1.25	1.36	1.30
Skewness	−0.785	−0.631	−0.0853	−0.691	0.787	−.0582	−0.498	−0.753	−0.805	−0.367	−0.584
Kurtosis	0.425	0.362	0.433	0.144	0.370	−0.094	−.150	0.331	0.415	−0.382	−0.002

Note. Likert scale from 1 = “strongly disagree” to 6 = “strongly agree.

Cudeck (1993). Second, we examined the resulting model parameters and considered standardized factor loading (λ ≥ 0.30) to be substantial (Floyd & Widaman, 1995).

To interpret correlations in size, we followed the conventions proposed by Gignac and Szodorai (2016) for personality constructs $|r| \geq 0.10$ as small, $|r| \geq 0.20$ as typical, and $|r| \geq 0.30$ as big.

The distributional properties of the items are shown, and the inter-item correlations in Table 3.

4.3. Results

4.3.1. Factorial validity

We used confirmatory factor analysis (CFA) to investigate the scale’s dimensionality. We first specified single factor models for each DSE dimension and evaluated the model fit. To further ensure the multidimensionality, we specified the following two models: a) a first-order correlated factor model in which items that belong to a distinct DSE dimension form one factor, whereby the factors are allowed to correlate, and b) a model with all items of all dimensions loading on one single factor (g-factor model). Table 4 shows the model fit indices of all models specified. Note that for iSE we displayed no model fit indices because this model has no degrees of freedom and shows therefore a perfect fit. Results point to a good model fit of the single models and a worse model fit of the g-factor model compared to the first-order correlated factor model, supporting multidimensionality.

Model fit of the single models were acceptable to good according to the Cut-Off values by (Hu & Bentler, 1999) (see Table 4). Concerning the RMSEA, according to Browne and Cudeck (1992), models indicate a mediocre fit with the exception of the dimension “problem-solving”.

The fully standardized factor loadings (see Table 5) are all above 0.50, indicating good discriminatory power of the items. Descriptive statistics of the single items of the scale show sufficient variation in the sample indicated by the size of the standard deviations of the single items (see Table 2). The scale means were slightly above the average of the scale (6-point Likert scale) (see Table 6).

4.3.2. Objectivity

The written instructions, the labeled categories, fixed scoring rules, and the reference data ensured the objectivity of the scale’s application, evaluation, and interpretation.

4.3.3. Reliability

For the different dimensions, reliability estimates calculated with McDonald’s Omega were as follows: information and data

DSE31	DSE32	DSE33	DSE34	DSE41	DSE42	DSE43A	DSE43B	DSE44	DSE51A	DSE51B	DSE52	DSE53	DSE54
1.000													
0.860	1.000												
0.603	0.602	1.000											
0.450	0.489	0.541	1.000										
0.554	0.551	0.705	0.615	1.000									
0.597	0.586	0.686	0.566	0.869	1.000								
0.576	0.573	0.683	0.514	0.704	0.734	1.000							
0.555	0.581	0.641	0.503	0.674	0.692	0.748	1.000						
0.564	0.593	0.685	0.540	0.675	0.704	0.784	0.809	1.000					
0.644	0.649	0.724	0.581	0.737	0.728	0.698	0.728	0.755	1.000				
0.609	0.614	0.678	0.615	0.727	0.728	0.668	0.689	0.703	0.819	1.000			
0.618	0.660	0.687	0.620	0.732	0.721	0.685	0.692	0.694	0.761	0.811	1.000		
0.526	0.583	0.597	0.686	0.634	0.623	0.594	0.612	0.637	0.649	0.707	0.747	1.000	
0.615	0.630	0.674	0.535	0.664	0.669	0.663	0.691	0.688	0.722	0.698	0.744	0.714	1.000
4.17	3.92	3.81	3.14	3.951	3.95	3.96	3.87	3.86	3.87	3.74	3.76	3.34	3.79
1.29	1.32	1.33	1.49	1.32	1.32	1.30	1.30	1.28	1.29	1.33	1.32	1.45	1.36
−0.640	−0.360	−0.352	0.129	−0.460	−0.432	−0.501	−0.394	−0.449	−0.438	−0.342	−0.321	−.0.011	−0.399
0.099	−0.281	−0.343	−903	−0.312	−0.258	-0–100	−0.269	−0.173	−0.176	−0.411	−0.229	−0.776	−0.330

literacy (iSE) Ω = 0.887 (95%Bootstrap CI[0.860;.908]), communication and collaboration (cSE) Ω = 0.749 (95%Bootstrap CI [0.740;.758]), digital content creation (dSE) Ω = 0.811 (95%Bootstrap CI[0.777;.844]), safety Ω = 0.921 (95%Bootstrap CI [0.904;.934]), and problem-solving (pSE) Ω = 0.659 (95%Bootstrap CI[0.647;.670]).

Test-retest-reliability is $r = 0.593$, $p < .001$ for Information and data literacy (iSE), $r = 0.590$, $p < .001$ for communication and collaboration (cSE), $r = 0.768$, $p < .001$ for digital content creation (dSE), $r = 0.681$, $p < .001$, for safety (sSE), $r = 0.715$, $p < .001$ for problem-solving (pSE). In sum, test-retest reliability is acceptable given the length of the time interval.

4.3.4. *Validation*

4.3.4.1. Nomological network. Convergent and divergent/discriminant validity

As outlined in section 2.2., digital self-efficacy is related to affective measures, individual characteristics, personality, and behavioral measures.

Table 7 shows the latent correlations among DSE dimensions and measures used to validate the scale.

Affective measure. In line with results from previous studies, all DSE dimensions were significantly negatively related to technophobia medium to high in effect size.

Individual characteristics. As assumed, gender differences with females showing a lower value in DSEs. Interestingly, they were only found for dSE, sSE, and pSE. The same applies to age differences in DSE dimensions; age differences were found only in dSE and sSE, with older people showing lower values in self-efficacy. However, the effects were negligible in size. Further, educational level is

Table 4
Structural models of DSE.

	$X^2(df)$, *SCF*	*p*	CFI	RMSEA [90% CI]	SRMR
cSE	1116.230 (20) 2.1293	$p < .001$	.947	.092 [.076; .108]	.033
dSE (corr31,32)	4.476 (1), 0.9834	$p = .034$	.996	.078 [.017; .157]	.006
sSE (corr41,42)	10.387 (4), 1.9668	$p = .034$	.994	.053 [.013; .094]	.014
pSE (corr 51a,51b)	38.312 (5), 1.9859	$p < .001$	.970	.108 [.078; .141]	.022
g-factor model	2250.477 (272), 1.5421	$p < .001$	.790	.113 [.109; .117]	.088
First-order correlated factor model	940.040 (262), 1.5221	$p < .001$	.928	.067 [.063; .072]	.059

Note. SCF Scaling correction factor; cSE = communication and collaboration; sSE = safety; dSE = digital content creation; pSE = problem-solving. In model sSE and correlated residuals were specified. In the G-factor model and First-order correlated factor model residual covariances is specified.

Table 5
Factor loadings of the single models.

	cSE	iSE	dSE	sSE	pSE
DSE11	.899				
DSE12	.798				
DSE13	.851				
DSE21		.875			
DSE22		.876			
DSE23A		.823			
DSE23B		.765			
DSE24		.892			
DSE25		.875			
DSE26A		.716			
DSE26B		.820			
DSE31			.717		
DSE32			.731		
DSE33			.831		
DSE34			.651		
DSE41				.771	
DSE42				.800	
DSE43A				.872	
DSE43B				.877	
DSE44				.903	
DSE51A					.833
DSE51B					.872
DSE52					.914
DSE53					.819
DSE54					.828

Note. All factor loadings are significant at $p < .001$. iSE = information and data literacy; cSE = communication and collaboration; dSE = digital content creation; sSE = safety; pSE = problem-solving.

Table 6
Means (M), Standard Deviations (SD), Skewness, Kurtosis of the Manifest Scale Score.

	M (*SD*)	Skewness	Kurtosis	Range	% with	20%/60%	Percentiles	Median
				Maximum	Min/Max		40%/80%	
iSE	4.409 (1.113)	−0.901	1.015	1–6	2.80/9.46	3.667/4.667	4.000/5.333	4.670
cSE	4.175 (1.105)	−0.760	0.748	1–6	2.63/5.78	3.429/4.571	4.000/5.000	4.286
dSE	3.758 (1.272)	−0.376	0.126	1–6	4.03/3.85	3.000/4.000	3.500/4.750	3.750
sSE	3.919 (1.343)	−0.531	0.314	1–6	4.55/5.60	3.000/4.200	3.800/5.000	4.000
pSE	3.699 (1.439)	−0.289	−0.125	1–6	4.38/5.08	2.800/4.000	3.600/4.600	3.800

Note. Main survey sample $N = 571$. Scale ranging from 1 to 6. iSE = information and data literacy; cSE = communication and collaboration; dSE = digital content creation; sSE = safety; pSE = problem-solving.

related to some DSE dimensions. Individuals with a medium educational level or a high educational level showed higher values in iSE, cSE, dSE compared to those with a lower educational level. Regarding sSE only individuals with a medium educational level showed higher values. Regarding pSE, only individuals with a high educational level showed a higher value in this dimension than low educated. Effect sizes were negligible or small. Moreover, employment status is correlated with iSE and cSE, indicating that employed individuals showed higher self-efficacy in these dimensions. Effects were negligible in size.

Personality. In line with the theoretical closeness of self-efficacy and internal locus of control*,* we found large positive correlations among the single dimensions of DSE with internal locus of control. We found a mixed pattern of effects, negligible in size and non-significant, among External locus of control and emotional instability.

Behavioral measures. The six kinds of frequency of use of ICT are correlated with the DSE dimensions with low to high effect sizes. The correlational pattern was as follows: Frequency of use of *programming and coding* was descriptively most strongly related with pSE ($r = 0.529$, $p < .001$) which was expected because programming and coding is the core part of pSE. Frequency of use of *searching in the internet* and *the use of e-mails* was descriptively most strongly related to iSE, which was expected because competent internet use and interact with others in digital environments are core features of this dimension. Frequency of use of *spreadsheets, word processing programs, and online conferences/chats* were descriptively most strongly correlated with dSE, which matches the description of the competencies in these areas. Frequency of use of online payment systems was descriptively most strongly related to iSE.

4.3.4.2. Fairness. We tested measurement invariance across gender using a multi-group confirmatory factor analysis (MG-CFA). As a first step, we specified the measurement model for each gender separately to investigate if configural measurement invariance (MI) is met. If the model fit of the measurement model is acceptable in each group, then configural MI is ensured. In the next step, we specified the multi-group models configural model (no constraints between parameters between the groups), metric, scalar, and strict models

Table 7
Nomological Network of the Single DSE dimensions (iSE, cSE, dSE, sSE, pSE) based on Latent Correlations.

Dimension	iSE	cSE	dSE	sSE	pSE
Technophobia	−.292***	**−.303*****	−.229**	−.166*	−.196**
Frequency of use of [a]					
Emails	**.393*****	**.332*****	**.316*****	**.315*****	.286***
Internet	**.421*****	**.395*****	**.378*****	**.356*****	**.346*****
Payment services	**.330*****	**.317*****	**.321*****	.293***	.273***
Spreadsheet programs	**.448*****	**.436*****	**.511*****	**.393*****	**.417*****
Online conferences/chats	**.423*****	**.452*****	**.508*****	**.373*****	**.388*****
Text processing programs	**.497*****	**.494*****	**.524*****	**.405*****	**.418*****
Programming and coding	.162**	.239***	**.523*****	**.445*****	**.529*****
Age	−.035	−.080	−.132**	−.066	−.104*
Education1 (1 = mid education)[a]	.215***	.193***	.127*	.103*	.093
Education2 (1 = high educated)[a]	.265***	.221***	.205***	.085	.104*
Employed vs. non-employed (1 = non-employed)[b]	−.090*	−.045	−.041	−.033	−.024
Gender[c]	.020	.009	−.102*	−.116**	−.199***
Internal locus of control	**.410*****	**.400*****	**.406*****	**.355*****	.294**
External locus of control	−.052	−.116	−.032	−.025	.008
Emotional instability	−.059	−.066	−.021	.022	.003

Note. $N = 571$˙ Following Gignac and Szodorai (2016) strong effects ($|r| \geq 0.30$) are bold. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < 001$.

[a] 0 = low educational level.

[b] 0= employed.

[c] 0 = male. iSE = information and data literacy; cSE = communication and collaboration; sSE = safety; dSE = digital content creation; pSE = problem-solving.

and inspected the differences in CFI between the models were below the cut-off values proposed by Cheung and Rensvold (2002) to be fulfilled to ensure measurement. The difference in CFI ≥ |.01| signal lack of invariance between nested models. As the Chi^2 difference tests depend on the sample size, we refrain from using the results for evaluation of MI.

Measurement models of each DSE dimension showed an acceptable fit in each group to confirm configural MI. The inspection of the differences in CFI and RMSEA between the nested models (i.e., configural, metric, scalar, strict models) confirmed at least partial strict MI with exception of iSE (see Table A4). Partial measurement invariance was achieved by relaxing constraints on residual variances (inspection of modindices). (Partial) strict MI implies that manifest scale scores can be recommended for analyses.

5. Discussion

In the first part of this paper, we presented a systematic scoping review to gain an overview of existing scales measuring self-efficacy related to digital system use and highlighted limitations of current measures. As a result of the review, it became apparent that even though there are a plethora of scales, there is still a lack of scales that (1) are theoretically-grounded multi-dimensional measures of DSE, encompassing diverse digital competence areas, (2) cover different functions and tasks of digital systems, (3) are independent of a specific digital system (e.g., Word), and (4) are also economical.

In the second part of this paper, we developed and validated a new economical DSE scale (median procession time of 0.75 min [25th percentile .3667, 50th 0.7500, 75th 1.2167]). The scale assesses multi-dimensional DSE, theoretically grounded in the DigComp2.1. framework of digital competences (Carretero et al., 2017) and is stringently derived from the concept of self-efficacy as defined in social cognitive theory by Bandura (1977, 1986, 1997). We validated the scale in a heterogeneous German sample and showed good reliability and validity. Partial strict measurement invariance of the scale across gender allows investigating research questions on gender differences based on manifest DSE scale scores. The developed scale can be used in survey research in the adult population (18–69) in individuals who have access to digital systems and are computer literate to a certain level.

Theory-consistent correlations between DSE dimensions and different kinds of frequency of ICT use highlight the multidimensionality of DSE in a between-network approach as well as factor analysis in a within-network approach of construct validation (Byrne, 1984). The pattern of correlations with relevant behavioral and personality variables (i.e., the nomological network) confirms the convergent and discriminant validity of the DSE scale. The analyses further highlight the construct's relevance. Results indicate relationships between DSE and actual technology use and technophobia. The high correlations with measures of actual technology use can be interpreted as evidence for criterion-based validity. As one of the first DSE scales to consider the competence dimensions of safety and problem-solving, the scale offers new insights regarding the relationship between these dimensions and ICT use. In our sample, both dimensions have medium to high correlations with each ICT use category. This underlines the importance of including safety and problem-solving as central digital competences towards which individuals develop self-efficacy.

5.1. *Limitations and future research*

Some limitations of the present study point to implications for further investigations. First, our sample was restricted to participants taking part in a web-based survey (CASI). Thus, generalizing our results to the overall population, mainly including individuals who lack a certain degree of computer literacy or do not have computer access, should be investigated in further studies. However, it can be assumed that with regards to a German population sample, for which this scale was developed, the majority of the population has access to digital systems. Results from the German PIAAC sample, for instance, showed that only 11.6% of the population had no computer experience or failed a basic computer test (OECD average: 14.2%; OECD Skills Outlook2013, 2013, pp. 87–88).

Second, thus far, the scale is validated in the German language, which limits the application field to a German-speaking population. The validation of the English-language adaptation of the scale is currently pending.

Third, although we provided first evidence for criterion-based validity of the scale, further studies should focus on the scale's criterion-based validity (i.e., ability or achievement test). To a certain extent, the correlations between frequency of use and DSE can be interpreted as evidence for (concurrent) criterion-based validity. This is because a higher frequency of use of digital systems should result in higher self-efficacy for using digital systems. However, test scores from ability or performance tests would be a more reliable criterion. In a meta-analytic review of tests that assess objective ICT skills, Siddiq et al. (2016) showed that most ICT skill tests assess only the skill facet *information*. Only a few tests assess the facets of *communication, collaboration, safety,* and *problem-solving*. Future test development is necessary to prove the criterion-based validity of the multidimensional DSE scale.

5.2. Implications

We consider the main application of this multidimensional DSE scale in assessing DSE in the adult population, for instance, in large-scale assessments evaluating self-efficacy relating to digital systems across life domains (e.g., private life and work). The new scale enables the investigation of several important questions concerning how digitalization affects the population and how individuals form competence beliefs.

For instance, the cSE dimension (Communication and Collaboration) can be used to investigate determinants of participation and usage behavior of social media in the population. Social media is becoming essential to participate in social life. Today, social media platforms such as Twitter play an important role not only in social interaction but also in political communication, with most countries and global political leaders represented on this platform and multiple others (e.g., Instagram, Facebook).

Furthermore, DSE may explain determinants of vocational choices and individuals' career development. Today most occupations are undergoing continuous digitalization (Kane et al., 2020; Palan & Schober, 2021). These digitalization processes come with changing job requirements, leading to a potential shift in competencies needed to succeed in digitalized sectors. Expectancy-value theories (e.g., Eccles & Wigfield, 2002) highlight the role of subject-related self-efficacy for vocational decisions. Particularly in job sectors that are prone to experience a digital transformation in the upcoming years, DSE may be an influential determinant of individuals' career choices and development.

Nevertheless, occupational groups in digitalized work domains will require different digital competences, which may further explain vocational choices for the particular occupational groups. For instance, software developers may need more advanced digital problem-solving skills than a social media marketing manager who will require more advanced digital communication skills. It can further be assumed that DSE and objective digital skills may be predictive for succeeding in that job sector where accelerated development of digital systems takes place.

6. Conclusion

The systematic review of DSE scales indicated a lack of scales that are grounded in integrated ICT competence frameworks, assess self-efficacy independent of specific systems or tasks, and have a broad application field. The newly developed DSE scale measures five dimensions related to the five digital competence areas suggested by the DigComp and the PIAAC model. Further, it is designed to measure DSE in the adult population (18–69) in a reliable, valid, and economical manner (completion time less than 1 min in CASI mode). Additionally, it allows to investigate research questions targeting gender differences in DSE. Due to its multidimensional structure, single dimensions can be used to investigate research questions in different contexts and disciplines. For instance, vocational choices or the use of social media in the population could be explored in large-scale assessments. When the English version of the DSE scale is validated, international comparisons of results will also be possible.

Credit author statement

Anna Sophie Ulfert-Blank, **Isabelle Schmidt**: Conceptualization, Methodology, Software, Data curation, Writing – original draft preparation, Visualization, Investigation. Supervision, Validation, Writing- Reviewing and Editing.

Declaration of competing interest

We have no conflicts of interest to disclose.

Data availability

Data will be made available on request.

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Appendix

Table A1
List of scales adapted in papers screened

Self-efficacy	Paper/Study	Measure	Included in review	Adapted in (Limited to sources in search)
Computer	Cassidy & Eachus (2002)	general	+	Mirza et al. (2006) Saleh (2008)
	Celik & Yesilyurt (2013) [h]	general	–	Saunders-Wyndham et al. (2021)
	Chou et al. (2010) [a]	unclear	–	Yen (2016)
	Compeau & Higgins (1995)	general	–	Laver et al. (2012) Lee et al. (2011) Hwang et al. (2016) Hsia et al. (2014) Cai et al. (2019) Jiang (2019) Khlaisang et al. (2021) Hidayat-ur-Rehman et al. (2020)
	Gist et al. (1989)	general	–	Reed et al. (2005)
	Murphy et al. (1989)	general	–	
	Ong et al. (2004) [d]	general	–	Zainab et al. (2017)
	Taylor & Todd (1995)	specific	–	Al-Otaibi and Houghton (2015) Zhang et al. (2012)
	Teo & Koh (2010)	general	–	Sarfo et al. (2017)
	Torkzadeh & Koufteros (1994) [b]	general	–	Baek (2014)
Internet	Eastin & LaRose (2000) [c]	general	–	Cao et al. (2016) Yang et al. (2007) Khang et al. (2014)
	Hsu & Chiu (2004) [d]	general	–	Change et al. (2012) Jiajun et al. (2019) Wang et al. (2021)
	Joo et al. (2000) [e]	general	–	Baturay (2011) Baturay and Bay (2010)
	Kim & Glassman (2013)	general	+	Sun et al. (2016)
	Tsai & Tsai (2003)	general	–	Chu and Tsai (2009) Chu and Chu (2010) Chan (2017) Yang (2012)
	Wu & Tsai (2006) [fg]	general	–	Tsai (2012)
	Zimmerman & Kulikowich (2016) [i]	general	+	Yavuzalp and Bahcivan (2020)
Technology	Miltiadou & Yu (2000)	general	–	Yukselturk (2009)
ICT	Fraillon et al. (2014)	general	–	Hatlevik et al. (2018)

Notes:
[a] Scale indicates to be a measure of self-efficacy but items represent measure of other construct (e.g., ease of use).
[b] Adapted from Murphy et al., 1989.
[c] Adapted from Compeau & Higgins, 1995.
[d] Adapted from Torkzadeh & Van Dyke, 2001.
[e] Adapted from Ertmer et al., 1994; Murphy et al., 1989.
[f] Adapted from Tsai & Tsai, 2003.
[g] Adapted from Tsai & Lin, 2004.
[h] Adapted from Aşkar & Umay, 2001.
[i] measure focused on online learning.

Table A.2
Demographic Characteristics of Participants.

Gender	
Female (%)	51.0
Age	
Range (years)	18–69
M (years)	43.55
SD (years)	14.72
Education [a]	

(*continued on next page*)

Table A.2 (*continued*)

Low (%)	37.4
Intermediate (%)	31.4
High (%)	31.2
Employment status	
Employed	54.3
Self-employed	5.3
Out of work …	
and looking for work	6.0
and not looking for work	3.0
Doing housework	5.4
Pupil/student	4.9
Apprentice/internship	2.8
Retired	16.6
Other	1.8

Note. N= 571.

[a] Low = no educational qualification; lower secondary leaving certificate; Intermediate = intermediate school-leaving certificate; high = higher education entrance qualification. We assessed employment status as used in PIAAC study (OECD). 1 = employed, 2 = self-employed, 3 = out of work and looking for work, 4 = out of work but not currently looking for work, 5 = doing housework, 6 = pupil/student, 7 = apprentice/internship, 8 = retired, 9 = none of what is mentioned above. For analyses, we dummy-coded employment status: employed (1,2,7) vs. non-employed (3,4,5,6,8,9).

Digital Self-efficacy Scale

Instruction

Instructions were provided in German: Im Folgenden werden Ihnen Fragen zum Umgang mit digitalen Systemen gestellt. Unter digitalen Systemen versteht man digitale Anwendungen (z. B. Software oder Apps), digitale Geräte (z. B. Computer oder Smartphone) sowie digitale Umgebungen (z. B. Internet oder Messenger-Dienste). English translation: We will now ask you how you use digital systems. Digital systems are digital applications (e.g., software or apps), digital devices (e.g., computers or smartphones), and digital environments (e.g., the internet or messaging services).

Response specifications

Participants respond to the items on a six-point Likert scale. In the German scale the response categories (translated in English) are (1) completely disagree (2) disagree (3) slightly disagree (4) slightly agree (5) agree (6) completely agree.

Table A.3
Items of the Scale DSE.

Coding	Items_German	Items_English	Dimension/Subscale
dse11	… in digitalen Umgebungen benötigte Informationen zu suchen.	search for specific information in digital environments.	Information and data literacy (iSE)
dse12	… richtige von falschen digitalen Informationen zu unterscheiden	distinguish between correct and incorrect digital information.	
dse13	… digitale Inhalte so zu speichern und zu organisieren, dass ich sie leicht wiederfinde.	store and organize digital content so that I can easily find it again.	
dse21	… mich mit anderen in digitalen Umgebungen auszutauschen.	interact with others in digital environments.	Communication and collaboration (cSE)
dse22	… Informationen und Daten mit anderen digital zu teilen.	share information and data with others digitally.	
dse23a	… an öffentlichen Diskussionen und Aktivitäten in digitalen Umgebungen teilzunehmen.	participate in public discussions and activities in digital environments.	
dse23b	… mich gegen Ungerechtigkeiten in digitalen Umgebungen zu wehren.	Defend myself against injustice in digital environments. Defend myself and others against injustice in digital environments. Push back against injustice in digital environments.	
dse24	… digitale Systeme für die Zusammenarbeit mit anderen zu nutzen.	use digital systems to collaborate with others.	

(*continued on next page*)

Table A.3 (*continued*)

Coding	Items_German	Items_English	Dimension/Subscale
dse25	… die richtige Umgangsform im Kommunizieren in digitalen Umgebungen zu verwenden.	use the proper etiquette to communicate in digital environments.	
dse26a	… meinen digitalen Fuβabdruck zu verwalten und zu löschen.	manage and delete my digital footprint.	
dse26b	… mich als Person in digitalen Umgebungen so zu präsentieren, wie ich das möchte.	present myself the way I want in digital environments.	
dse31	… digitale Inhalte zu erstellen.	create digital content.	Digital content creation (dSE)
dse32	… digitale Inhalte so zu verändern, dass neue Inhalte entstehen.	change digital content in a way that new content is created.	
dse33	… rechtliche Aspekte, wie Nutzungsbedingungen und Lizenzen, in digitalen Umgebungen zu erkennen.	identify legal aspects in digital environments, such as terms of use and licenses.	
dse34	… einen einfachen Befehl in einer Programmiersprache zu schreiben.	write a simple command in a programming language.	
dse41	… meine digitalen Endgeräte vor ungewolltem Zugriff zu schützen.	protect my digital devices from unwanted access.	Safety (sSe)
dse42	… meine persönlichen Daten in digitalen Umgebungen zu schützen.	protect my personal data in digital environments.	
dse43a	… gesundheitliche Risiken im Umgang mit digitalen Umgebungen zu erkennen.	recognize health risks associated with using digital environments.	
dse43b	… digitale Umgebungen zur Förderung meiner Gesundheit nutzen.	use digital environments to promote my health.	
dse44	… den Einfluss digitaler Umgebungen auf die Umwelt zu erkennen.	recognize the impact of digital environments on nature and the climate.	
dse51a	… auftretende technische Probleme in digitalen Umgebungen zu erkennen.	identify technical problems when using digital environments.	Problem-solving (pSE)
dse51b	… bei auftretenden technischen Problemen verschiedene Lösungen zu finden und anzuwenden.	find and apply various solutions to technical problems that arise.	
dse52	… bei nicht technischen Herausforderungen das passende digitale System zu finden.	find the right digital system to meet non-technical challenges.	
dse53	… neuartige digitale Lösungen für Fragestellungen zu entwickeln.	develop novel digital solutions.	
dse54	… eigene fehlende digitale Kompetenzen zu erkennen und zu verbessern.	identify and improve the digital skills I lack.	

Table A.4
Results of Measurement Invariance Testing over Gender for Each of the Five DSE Dimensions.

Dimension	Model	$X^2(df), p, SCF$	$\Delta X^2(df), p$	CFI	ΔCFI	RMSEA (95% CI)	SRMR
information and data literacy (iSE)	women[a]	0.000 (0), p < .001, 1.000		1.00		.000 [.000; .000]	.000
	men[a]	0.000 (0), p < .001, 1.000		1.00		.000 [.000; .000]	.000
	Configural [a] Model	0.000 (0), p < .001, 1.000		1.00		.000 [.000; .000]	.000
	metric Model	5.957 (2), p = .0509, .9329		.993		.083 [.000; .164]	.058
	scalar Model	17.184 (4), p = .0018, .9665		.975	.018	.107 [.059 .162]	.038
						.060 [.000 .129]	.058
	Partial scalar model (Intercept dse12 freed)	6.091 (3), p = .1072, .9618		.994	.001		
	strict	15.228 (6), p = .0186, 1.4180		.983	.011	.073 [.028 .120]	.041
communication and collaboration (cSE)	women	78.314 (20), p < .001, 1.9565		.944		.100 [.077 .124]	.036
	men	64.017 (20), p < .001, 2.1022		.948		.089 [.065 .113]	.034
	Configural Model	141.818 (40), p < .001, 2.0293		.946		.094 [.078 .112]	.035
	metric Model	159.716 (47), p < .001, 1.8519	9.531 (7), *p* = .0486	.940	.006	.092 [.076 .104]	.046
	scalar Model	177.698 (54), p < .001, 1.7438	13.841 (7), *p* = .0541	.934	.006	.090 [.075 .104]	.059
	strict	175.294 (62), p < 001, 1.8485		.940	.006	.080 [.066 .094]	.056
digital content creation (dSE)	women	0.002 (1), *p* = .9607, 1.0776		1.00		.000 [.000 .000]	.000
	men	8.629 (1), *p*= .0033, .9414		.982		.165 [.077 .274]	.012

(*continued on next page*)

Table A.4 (*continued*)

Dimension	Model	$X^2(df), p, SCF$	$\Delta\ X^2(df),\ p$	CFI	ΔCFI	RMSEA (95% CI)	SRMR
	Configural Model	8.049 (2), p= .0179, 1.0097		.994		.103 [.036 .182]	.009
	metric Model	13.945 (5), p = .0160 .9962	5.840 (3), p = .1196	.991	.003	.079 [.031 .130]	.043
	scalar Model	31.072 (8), p < .001, .9999	17.074 (3), p = .0007	.976	.015	.101 [.065 .139]	.039
	Partial scalar model (Intercept dse34 freed)	16.128 (7), p= .0240, 1.0034	2.2428 (2), p= 1.000	.990	.001	.068 [.023 .112]	.044
	Strict Model	23.748 (11), p = .0138, 1.1206	7.8669 (4), p = .0966	.986	.004	.064[.028 .099]	.067
safety (sSE)	women	3.261 (4), p = .5151, 1.9828		1.00		.000 [.000 .081]	.010
	men	10.726 (4), p= .0298, 1.9676		.989		.077 [.022 .135]	.018
	Configural Model	13.959 (8), p= .0828, 1.9752		.995		.051 [.000 .095]	.014
	metric Model	21.786 (12), p= .0400, 1.5841	8.654 (4), p= .0703	.992	.003	.053 [.011 .089]	.052
	scalar Model	30.347 (16), p= .0163, 1.4372	9.135 (4) p= .0578	.988	.004	056 [.024 .086]	.045
	Strict	42.691 (21), p = .0034, 1.5395		.982	.006	.060 [.034 .086]	.040
Problem-solving (pSE)	women	11.396 (4), p = .0225, 1.8809		.985		.080 [.027 .136]	.018
	men	11.586 (4), p< .001, 1.3783		.988		.082 [.029 .140]	.013
	Configural Model	22.955 (8), p = .0034, 1.6296		.986		.081 [.043 .121]	.016
	metric Model	31.297 (12), p = .0018, 1.4043	6.861 (4), p = .1434	.982	.004	.075 [.043 .108]	.042
	scalar Model	37.675 (16), p = .0017, 1.3063	5.058 (4), p = .2673	.980	.002	.069 [.040 .098]	.044
	Strict	36.890 (22), p = .0243, 1.5768		.986	+.006	.049 [.018; .075]	.030

Note.

[a] The model shows a perfect fit because they are just identified. $N = 571$; women $n = 291$, men $n = 280$; CFI = comparative fit index; RMSEA = root mean square error of approximation; SCF = scaling correction factor; CI = confidence interval. SBχ2 = Satorra-Bentler scaled chi-square difference test.

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