Navigating the Landscape of Digital Competence Frameworks: A Systematic Analysis of AI Coverage and Adaptability

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Abstract: The rapidly evolving capabilities of generative artificial intelligence (AI) in understanding and generating texts and images challenge the role of human competences in existing and redesigned processes and infrastructures in many domains. In addition to aspects such as automating complex tasks and decision-making processes, the question arises as to which human competences are required to deal efficiently and confidently with these newly emerging AI-driven opportunities, manifesting in form of new tools, methods, processes and infrastructures, including the design and use of hybrid human-AI ecosystems. A variety of digital competence frameworks (DCFWs) is available to support practitioners from didactic and business contexts in specifying and measuring such competences. In this paper, we systematically analyze established DCFWs and compare the provided means to cope with the challenges from rapidly evolving generative AI. For this purpose, we present the results of a systematic mapping study (SMS) based on 25 identified international DCFWs, focusing on the degree of AI coverage and adaptability. The resulting structural overview and comparative analysis provides orientation and aims to empower both individual practitioners and organizations to evaluate, select, combine, contextualize, adapt and apply existing frameworks based on their individual application purposes.

1 INTRODUCTION

OpenAI's launch of *ChatGPT* (OpenAI, 2022) at the end of 2022 has brought attention (Johnson, 2022) to large language models (LLM) and generative AI in general. It also raised awareness to questioning AI's impact on human competences (Shiohira, 2021). A rapidly transforming AI landscape continuously impacts and challenges society, economy and education. As new tools and applications are emerging, they not only represent technological advances, but also raise critical questions about how these changes will transform processes, infrastructures, and the role of humans (Llaneras et al., 2023; Nature Machine Intelligence, 2023). For instance, questions arise such as to what extent practitioners and organizations are prepared for the effects of massive technological shifts on labour (Zarifhonarvar, 2023) and education (Chiu et al., 2023), and how they can be supported by research to adapt accordingly. To address this issue, analyzing established Digital Competence Frameworks (DCFW) could provide insights by elaborating their flexibility to adapt to new contexts in general as well as their integration of AI. Therefore this paper presents a comparative analysis of established DCFWs, aiming to provide orientation in an ever evolving field, trying to keep up with the pace of technological development. In this endeavour, a *systematic mapping study* (SMS) was conducted to examine, compare and *map* a selection of 25 DCFWs in an iterative process. Based on a structural overview of DCFW characteristics, we further investigated criteria for categorizing the DCFWs in terms of adaptability for specifying competences and coverage of AI competences. In particular, this paper provides the following **contributions**:

1. We present a *systematic overview* and comparison of established *digital competence frameworks (DCFWs)*.
2. In addition, we report on the results of a *comparative analysis* of the extent to which DCFWs (a) address *AI competences* and (b) provide *adaptability* for competence specification.

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The resulting structural overview with emphasis on the level of adaptability for competence specification by users as well as the coverage of AI competences, provides orientation and guidance for both individual practitioners and organizations. For instance, it supports experts in didactic or business contexts seeking to leverage such frameworks for specifying AI-related competences, such as for defining learning objectives, assessing actual competences, or specifying requirements for project staffing.

Paper Structure. The remainder of this paper is structured as follows: Section 2 provides background and related work on digital competences and frameworks. The applied approach and research methodology are outlined in Section 3. In Section 4, we present the findings of our systematic mapping study (SMS) in terms of the analysis and comparison of frameworks. Section 5 discusses limitations and challenges. Finally, Section 6 concludes the paper.

2 BACKGROUND & RELATED WORK

In this section, we discuss definitions and relevant concepts of digital competences (Section 2.1), outline structural components of digital competence frameworks (DCFWs; Section 2.2), and give an overview of how these frameworks have been investigated in previous research (Section 2.3).

2.1 Digital Competences

Exploring the terminology around digital competences (DC) in scientific literature as well as in the analyzed DCFWs, it becomes manifest that on the one hand the term 'digital competence' lacks a clear definition. On the other hand, there are multiple terms that are used synonymously or similarly next to each other, such as 'competence', 'literacy' and 'skill'; also see (Ferrari et al., 2012; Martínez et al., 2021; Mattar et al., 2022; Sánchez-Canut et al., 2023). Understanding DC as a boundary concept, (Ilomäki et al., 2016) emphasizes that, considering the pace of technological development, a definition for the concept of DC should be wide enough to accommodate these circumstance and therefore not to strongly be driven by a technology perspective, which is supported by (Martínez et al., 2021) concluding that it "consolidates the techno-social perspective for empowerment and technological appropriation, which exceeds the operational use of tools". For this paper, we refrain from including a category for these definitions, because it would go beyond the intended scope and does not quite touch on our research questions. Also previous work on comparing DCFWs has already dealt with this topic thoroughly. Confronted with 16 different concepts, we pragmatically decided to adopt the term 'competence', as used by the majority of the reviewed DCFWs.

2.2 Digital Competence Frameworks

In the following, we outline the purpose and structural components of digital competence frameworks (DCFWs). In general, frameworks, taxonomies and models play a crucial role in structuring and systematizing competences. They provide a general orientation to help organizations remain competitive and meet current (digital) standards. There are already well established generic models and frameworks in the education sector, such as Bloom's *Taxonomy of Learning Objectives* (Krathwohl, 2002) or the *Technological Pedagogical Content Knowledge (TPACK)* framework, which "attempts to capture some of the essential qualities of teacher knowledge required for technology integration in teaching" (Mishra and Koehler, 2006). In addition, also frameworks for specific application domains such as software refactoring are in usage (Haendler and Neumann, 2019). Such structures are essential to provide clear and consistent benchmarks for the development of competencies. Digital Competence Frameworks are supposed to provide a comprehensive tool to ensure a common understanding of what constitutes DC by fostering standardization and consistency. They give guidance for digital skill development as well as assistance to make informed design choices, therefore allowing continuous relevance of curricula and training programs regarding emergent technologies (UNESCO, 2023). Generally, a DCFW consists at least of the defined competence areas or dimensions, often sub-divided in further competences, and proficiency levels specific to each DCFW (UNESCO, 2023).

Current research attempts to span the bridge from digital to AI competences. By exploring the concepts of AI literacy, (Ng et al., 2021) derives general recommendations for AI literacy in education. From an HCI perspective, (Long et al., 2022) extracts "a set of AI literacy competences and design considerations", while (Ng et al., 2023) identifies challenges teachers may be facing when including AI tools into their teaching practice (e.g., ethical concerns). (Santana and Díaz-Fernández, 2023) examines competences *for* AI from an HRM viewpoint presenting a "systematization and representation of the relationship between employee competences and AI". The Canadian AI competency Framework (Dawson College, 2021)

defines three competence domains in context with AI, encompassing competences focusing on project development (technical), on project planning and scaling (business) and on implementation and utilization (human) while integrating ethical competences into all domains. (Sattelmaier and Pawlowski, 2023) propose a framework for K-12 education, introducing 'AI competencies' (technical focus) and 'emerging competencies' (AI competences with a focus on generative AI), including ethical, social, and privacy implications on both levels.

2.3 Digital Competence Frameworks in Comparison

Most previous research on comparing and analyzing DCFWs has narrowed down their sample by aiming explicitly at teachers (Cabero-Almenara et al., 2020; Yang et al., 2021; Tomczyk and Fedeli, 2021; Benali and Mak, 2022) or education in general (Mattar et al., 2022), although with different focus and methods. (Sánchez-Canut et al., 2023) specifically analyzes "the existing definitions of professional DC, the frameworks used to develop it at the workplace, and the gender differences observed". (Ferrari, 2012) decided on a broader scope, aiming for a "fair distribution of target groups that the frameworks are addressed to". One approach that all the work just mentioned has in common is aligning and comparing DCFWs by competence area/dimension and proficiency levels (if given), examining them thoroughly and sufficiently, which is why we refrain from an in-depth analysis providing a quantitative overview instead. We observed that the need to differentiate between target group and target audience is certainly recognized (Rosado and Belisle, 2006; Mattar et al., 2022), however there is little consistency to be found when introducing these categories to clearly make this distinction. Facing a similar challenge, we will discuss our approach in Section 3.3. The category self-assessment is systematically defined by (Rosado and Belisle, 2006; Ferrari, 2012) and included by (Tomczyk and Fedeli, 2021; Yang et al., 2021), raising further questions concerning the validity of self-assessment tools and thus opens up a research direction which is beyond the scope of this work. Another interesting focus is presented by (Cabero-Almenara et al., 2020; Mattar et al., 2022) validating *The Digital Competence Framework for Citizens (DIGCOMP)* and *European Framework for the Digital Competence of Educators* (Benali and Mak, 2022), both DCFWs providing the basis for a new DCFW ecosystem. Comparing *DIGCOMPs* competences and competence areas with national digital competence curricula for schools, was chosen by (Siddiq, 2018) (Norway and Sweden) and (Hazar, 2019) (Turkey). Finally, most literature agrees that the characteristics of DCFWs are depending on context and cultural factors (Ilomäki et al., 2016; Yang et al., 2021) and objective and purpose and therefore are fluent. Although there has been research about the concepts aiming to define DC, the structure and dimensions of competence areas and proficiency levels in detail, little regard has been given to analysing DCFWs in view of adaptability and AI, except (Mattar et al., 2022) pointing out the few FWs already updated according to the impact of emerging tech, concluding that "digital competence frameworks need constant updates as technologies continuously evolve". This paper therefore aims to investigate this gap, by identifying categories to structure information about DCFWs, analyzing how much thought has been given to adaptability and exploring if and how (generative) AI was considered to be integrated.

3 SYSTEMATIC MAPPING PROCESS

This section outlines the applied research methodology. In order to develop an overview of established digital competence frameworks (DCFWs), our approach is following the process of a *systematic mapping study (SMS)*, which represents a kind of systematic literature review, but with an emphasis on elaborating a structural overview over a certain research domain by identifying appropriate means for quantifying and classifying the field (Kitchenham and Charters, 2007; Petersen et al., 2008; Ralph, P. et al., 2021). Proceeding from usage in medicine research, SMS nowadays represent a popular methodology in technical fields such as software engineering or information systems, see, e.g., (Zhao et al., 2021; Wolny et al., 2017). Fig. 1 illustrates the applied research process in terms of an activity diagram of the *Unified Modeling Language (UML2)* (Object Management Group, 2017). Departing from defining the review scope and corresponding research questions (see (1) in Fig. 1), we performed a combined structured search for DCFWs (see (2)). We then filtered the identified DCFWs by removing duplicates as well as by applying inclusion and exclusion criteria (see (3) and Tab. 1). Based on a first coarse structural analysis of the resulting DCFWs, we derived a classification scheme suitable to categorize the DCFWs, and extracted the corresponding data (see (4)). The following Sections 3.1 to 3.3 provide details on these steps.

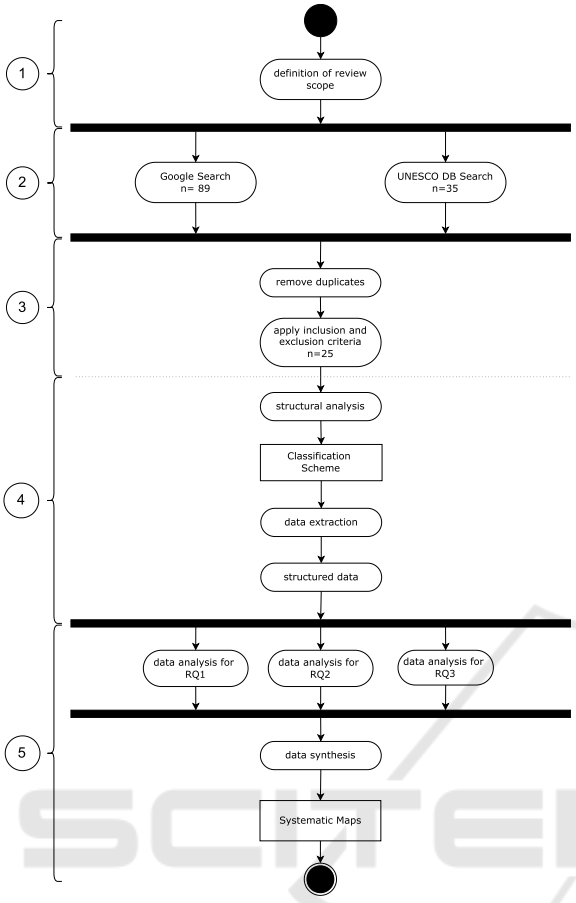

Figure 1: Applied research process to analyze established DCFWs in terms of a systematic mapping study.

The resulting findings in terms of structural characteristics of DCFWs and the derived systematic maps (see (5)) are reported in Section 4.

3.1 Review Scope & Research Questions

In order to address the question on the extent to which established DCFWs are suitable for specifying competences for generative AI, we defined the following research questions (RQ1–3) as starting point for our systematic mapping study (see (1) in Fig. 1).

RQ1. Which criteria are suitable to categorize and compare digital competence frameworks (DCFWs)?

RQ2. How do DCFWs provide adaptability for users to specify competences?

RQ3. How do DCFWs address competences for artificial intelligence (AI), especially generative AI?

3.2 Search & Selection of Frameworks

To identify established DCFWs, we conducted a structured search combining the use of a search engine and *snowballing* (Wohlin, 2014); for details, see below. Since most DCFWs are not published in terms of scientific literature, we combined *Google Scholar* and *Google* as search engines, ensuring not to oversee results. We defined and applied the following search string:

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(digital OR IT) AND (framework* OR reference* OR model*
OR taxonomy*) AND (competenc* OR literac* OR skill*) AND
AI
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Additionally, we restricted the search to PDF files published in English after 2017 (i.e., *filetype:pdf*, *after:2017*, and *lang:en*; also see Tab. 1). During literature search, a reference point we continuously stumbled upon was the *UNESCO-UNEVOC* database[1] providing a current overview of established DCFWs for teachers, learners and citizens. The referenced DCFWs can be searched by criteria relevant to the design, content, and use of digital skills. In addition to the search engine (see (2) in Fig. 1), we used this database to track the referenced DCFWs; also see *backward snowballing* (Wohlin, 2014). In particular, the *UNESCO* database has a total of 35 entries, structured into 27 DCFWs, five programs, two standards and one tool. For the purpose of our study, we only reflected DCFWs in the database explicitly categorized as a framework.

Table 1: Applied inclusion and exclusion criteria.

Inclusion	Exclusion
categorized as framework, applicable on at least local level	not available in English, published before 2017

After removing duplicates, we then filtered the remaining DCFWs according to the defined inclusion and exclusion criteria (see (3) in Fig. 1). In particular, we decided to exclude DCFWs not available in English, in order to focus on internationally accessible DCWFs–with the exception of *DigComp AT 2.3* (#06). In order to reflect the state-of-the-art of DCFWs, we excluded DCFWs published before 2017. Also, for comparability reasons, DCFWs which are not intended to be applicable on an at least regional level, such as frameworks published by universities, were excluded. The application of these inclusion and exclusion criteria results in 25 DCFWs

[1] Available at https://unevoc.unesco.org/home/Digital+Competence+Frameworks.

forming the basis for the further analysis (see (3) in Fig. 1). The selected DCFWs were then systematically organized by structural basic categories (i.e., title, description, origin, target group(s), publisher, year, geographical coverage). Information about the DCFWs was extracted and analyzed by two authors independently by examining the documents and websites provided by the DCFWs. The results then have been discussed and merged together in an iterative process in order to identify and synthesize suitable categories for a classification scheme, according to the guidelines for conducting systematic mapping studies in software engineering (Kitchenham and Charters, 2007). This collection of structural characteristics sets the foundation to answer RQ1 (see (4) in Fig. 1). For RQ2 and RQ3, we performed a similar process, consisting of the following three steps: (a) screening the DCFWs for relevant terms and criteria, (b) defining hierarchical levels (extent to which AI competences addressed and adaptability for users), and, finally, (c) assessing which levels are met by the DCFWs (see (5) in Fig. 1).

3.3 Classification Scheme

Here, we introduce the applied classification scheme (see Tab. 2). The scheme is structured into different categories, each characterized by properties, variations or levels, assigned to certain groups addressing the research questions (RQ1–3). The first set of categories (basic) was derived from the *UNESCO* database and validated through examining the DCFWs' documentations (i.e., regional scope, year of publication and how each DCFW defines the target group it is supposed to serve). This data has been amended by an identifier and code (i.e., DCFWs' abbreviations as given). To collect data on how the DCFWs are similar and where they differ (see RQ1/focus in Tab. 2), we took a closer look on how and to what extent (quantity) competence areas and proficiency levels are defined by the DCFWs. There are different approaches in related comparative work to introduce the category target group, as discussed in Section 2.3. Considering there are subtle differences when looking more closely at how DCFWs define whom they are aiming at, we sorted them accordingly to the intended purpose for each target group, finding four different aspects. First, there is an *audience*, which can be understood as the end users, such as students, learners or more broadly citizens, which are not supposed to educate themselves along any chosen DCFW. Then, there is the group of educators, who are able to *contextualize* a DCFW transferring it into their teaching practice as well as use self-assessment tools as foundation to develop their own DC. In terms of *application*, some DCFWs are supposed to be used as a starting point to develop policies or training programs, therefore aiming at stakeholders like labour market (social) partners, or non governmental organizations (NGOs). Another perspective, is whose purpose it is to *adapt* a DCFW by either updating or further developing it, which are fundamentally represented by public or private stakeholders, like curriculum developers or policy makers. In sum, target group is a complex category, strongly depending on purpose and context. For this reason, we introduced the category *sector*. Moreover, to addressing RQ1/supplement, we collected data about licence information, forming the basis for adaptability. Another important category related to adaptability is the extent to which support for practical application is given. These categories are extended by measuring tools and recommendations for self-assessment. In Section 4.1, we will explore the RQ groups basics, focus, and supplement in detail. To distinguish between the extent to which each DCFW provides adaptability for competence specification (RQ2), as well as if and how competences for (generative) AI are addressed (RQ3), we propose hierarchical levels (0–3), which we will presented in Sections 4.2 and 4.3.

4 MAPPING RESULTS

In this section, we present the results of our systematic mapping. In Section 4.1, we provide an overview of the structural characteristics (such as regional and sector-specific scopes) of DCFWs. Section 4.2 then provides details on how the frameworks support adaptability for users to specify competences. Section 4.3 reports on how AI competences are addressed by DCFWs. Finally, Section 4.4 discusses the results of mapping of adaptability and AI coverage.

4.1 Characteristics of Digital Competence Frameworks

In order to address RQ1 (*which criteria are suitable to categorize and compare DCFWs?*), we collected the structural characteristics of 25 DCFWs (according to the category groups basic, focus, and supplement in Tab. 2). These structural characteristics are presented in two parts. Tab. 3 provides basics such as the framework title, regional scope and the year of publication. In turn, Tab. 4 provides data on the other groups (i.e., focus, supplement, levels of adaptability and (gen)AI coverage). As two key criteria to distinguish the DCFWs, Fig. 2 illustrates the DCFWs'

Table 2: Applied classification scheme to analyze digital competence frameworks (DCFWs).

Category	Characteristics	RQ	Category Group
id (#)	assigned identifier	RQ1	basic
code	assigned abbreviation (code) for clarity		
framework title	full publication title		
region	`local`, `national`, `international`, `global`		
year	year of publication (latest version)		
targeted sector	sector aimed at	RQ1	focus
proficiency	quantity of proficiency levels		
competence areas	quantity of competence areas		
licence information	given licence information	RQ1	supplement
line application guidance	[`y`/`n`] support with utilization and implementation		
self-assessment	[`y`/`n`] tools or recommendations for self-assessment		
level of adaptability	`0` - none	RQ2	adaptability
	`1` - some context, templates		
	`2` - application scenarios, guidelines		
	`3` - specifically designed dimension for adaptability		
level of AI coverage	`0` - none	RQ3	(generative) AI
	`1` - as an example for technology		
	`2` - ethics, privacy; included into indicators		
	`3` - application scenarios		

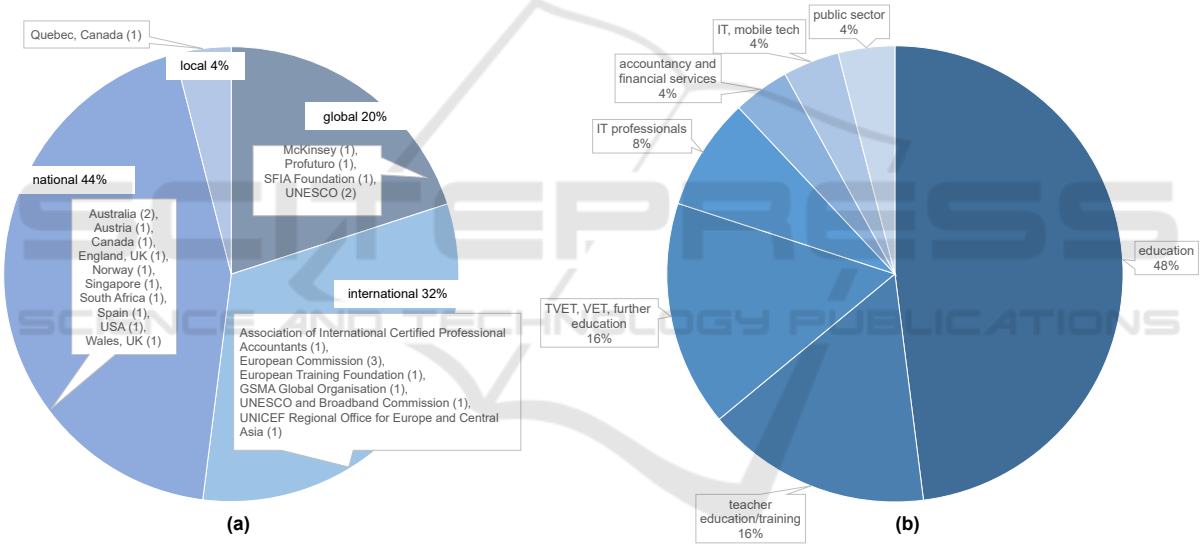

Figure 2: Regional (a) and sector-specific characteristics (b) of analyzed digital competence frameworks (DCFWs).

operational bounds (Rosado and Belisle, 2006) in terms of the distribution of addressed *regions* and *sectors* (Fig. 2 **(a)** and **(b)**, respectively).

Regional Scope. In particular, 44% (11) DCFWs are intended to be applied at a national and 32% (8) at an international level, 20% (5) are aiming at a global audience, just one DCFW operates within a `local` scope (4%); also see Fig. 2 (a). Among the DCFWs labeled `national`, five are European (AT #06, UK #08 and #12, NO #20, ES #03), two from Australia (#02, #11), two from North America (CS #25, US #24), one from Africa (ZA #19) and one from South-East Asia (SG #23). The label `international` includes the following organizations; *European Commission* (#09, #07, #04), *European Training Foundation* (#14), *UNESCO and Broadband Commission* (#30), *GSMA Global Organization* (#31), *Association of International Certified Professional Accountants* (#32), *UNICEF Regional Office for Europe and Central Asia* (#33). Publishers for a `global` audience are; *UNESCO* (#10, #17), *Profuturo* (#15), the *SFIA Foundation* (#22) and *McKinsey* (#18).

Targeted Sector. Moreover, as shown in detail in Fig. 2 (b), 48% of the DCFWs are aiming at the educational sector (#03, #04, #06, #07, #08, #09, #10, #13, #14, #15, #21, #25), 16% at teacher education/training (#17, #19, #20, #24), 16% at vocational

Table 3: Structural characteristics of analyzed digital competence frameworks *(part 1)*.

#	Code	Reference	Framework	Region	Year
#01	AIDTC	(Balbo Di Vinadio et al., 2022)	Artificial Intelligence and Digital Transformation Competencies for Civil Servants	International	2022
#02	AWDSF	(Gekara, V, Snell, D, 2019)	Skilling the Australian Workforce for the Digital Economy - The Australian Workforce Digital Skills Framework	National	2019
#03	CDCFT	(INTEF, 2017)	Common Digital Competence Framework for Teachers (CDCFT)	National	2017
#04	CFRIDiL	(Adami et al., 2019)	Common Framework of Reference for Intercultural Digital Literacies (CFRIDiL)	International	2019
#05	CGMA	(Association of International Certified Professional Accountants, 2019)	Competency Framework. Digital Skills (CGMA)	International	2019
#06	DCAT	(Nárosy et al., 2022)	DigComp 2.3. AT	National	2022
#07	DCEDU	(Redecker, 2017)	European Framework for the Digital Competence of Educators (DigCompEdu)	International	2017
#08	DCFWA	(Education Wales, UK, 2022)	Digital Competence Framework	National	2022
#09	DCOMP	(Vuorikari et al., 2022)	The Digital Competence Framework for Citizens (DigComp 2.2)	International	2022
#10	DLGF	(Law et al., 2018)	Digital Literacy Global Framework - A Global Framework of Reference on Digital Literacy Skills for Indicator 4.4.2	Global	2018
#11	DLSF	(Department of Education, Skills and Employment., 2020)	Digital Literacy Skills Framework (DLSF)	National	2021
#12	DTPF	(Education and Training Foundation, 2019)	Digital Teaching Professional Framework	National	2019
#13	EDCF	(Siina et al., 2022)	Educators' Digital Competency Framework	International	2022
#14	ETFM	(European Training Foundation, 2022)	ETF READY Model (Reference model for Educators' Activities and Development in the 21st-centurY)	International	2022
#15	GFEDC	(Trujillo Sáez et al., 2020)	The Global Framework for Educational Competence in the Digital Age	Global	2020
#16	GSMA	(Jacobs et al., 2021)	Developing mobile digital skills in low- and middle-income countries	International	2021
#17	ICTCFT	(Butcher, 2018)	UNESCO ICT Competency Framework for Teachers (ICT CFT) Version 3	Global	2018
#18	MKIN	(Dondi et al., 2019)	Defining the skills citizens will need in the future world of work (McKinsey)	Global	2019
#19	PDFDL	(Department of Education. SA, 2019)	Professional Development Framework for Digital Learning	National	2019
#20	PFDK	(Kelentrić et al., 2017)	Professional Digital Competence Framework for Teachers	National	2017
#21	QCDCF	(Ministère de l'Éducation et de l'Enseignement supérieur, 2019)	Quebec Digital Competency Framework	Local	2019
#22	SFIA	(SFIA Foundation, 2021)	Skills Framework for International Age (SFIA - 8)	Global	2021
#23	SKILL	(Government of Singapore, 2022)	SkillsFuture - Skills Framework for Infocomm Technology	National	2022
#24	TETC	(Foulger et al., 2017)	Teacher Educator Technology Competencies	National	2017
#25	UUEMLF	(Mediasmarts, 2022)	USE, UNDERSTAND & ENGAGE: A Digital Media Literacy Framework for Canadian Schools	National	2022

education and training (#02, #11, #12), 8% at IT professionals (#22, #23) while 4% each are directed at accountancy and financial services (#05), IT - mobile technology (#16), and public sector (#01).

Competence Areas and Proficiency Levels. In addition to these criteria, the DCFWs differ widely regarding *competence areas* ranging from 2 to 20 and *proficiency levels* from 0 to 9.

Table 4: Structural characteristics of analyzed digital competence frameworks *(part 2)*.

#	Code	Sector	Prof Level	Comp Areas	Licence	Appl. Guide	Self-Assess	Level Adapt	Level AI
#01	AIDTC	public sector	3	3	CC-BY-SA 3.0 IGO	y	y	2	**3**
#02	AWDSF	vocational education and training (VET) system	5	4	CC BY 3.0 AU	y	y	1	1
#03	CDCFT	education	6	5	CC BY SA	n	n	1	1
#04	CFRIDiL	education	3	**3+1**	n/a	y	y	**3**	0
#05	CGMA	accountancy and financial services	4	6	n/a	n	n	0	0
#06	DCAT	education	**8**	6	CC-BY-NC-ND-3.0-AT	y	y	1	2
#07	DCEDU	education	6	6	Reuse authorized, provided source is ack	y	y	1	0
#08	DCFWA	education	5	**4/12**	n/a	y	n	1	0
#09	DCOMP	education	4	5	CC BY 4.0	y	y	2	**3**
#10	DLGF	education	-	7	CC-BY-SA 3.0 IGO	y	n	2	0
#11	DLSF	vocational education and training (VET) system	5	**2**	CC BY-NC-SA 3.0	y	y	1	0
#12	DTPF	technical vocational education and training (TVET)	3	7	n/a	y	n	2	2
#13	EDCF	education	-	**20**	n/a but funded by the EU	y	y	1	0
#14	ETFM	education	-	**6+1**	CC BY 4.0	y	y	**3**	0
#15	GFEDC	education	3	3	n/a	y	n	1	0
#16	GSMA	IT, mobile technology	3	6	n/a	y	y	2	0
#17	ICTCFT	teacher-training	3	6	CC BY-SA 3.0 IGO	y	y	2	**3**
#18	MKIN	future world of work	-	13	n/a	n	n	0	0
#19	PDFDL	teacher-training	-	13	n/a	n	y	2	0
#20	PFDK	teacher education	3	7	CC BY-SA 3.0 NO	n	y	1	0
#21	QCDCF	education	-	12	n/a	y	n	2	2
#22	SFIA	IT professionals	7	6	free for personal use, commercial license	y	y	2	0
#23	SKILL	IT professionals	-	8	n/a	y	y	2	1
#24	TETC	teacher education	-	12	n/a	y	n	2	0
#25	UUEMLF	education	-	9	n/a	y	y	1	0

Supplemental Materials. 13 out of 25 DCFWs provide *licence information*, nine of which are licensed as a derivative of *CC BY*, encouraging adaptations, except #06 surprisingly using *CC-BY-NC-ND*, whereby *ND* stands for *No derivatives or adaptations of the work are permitted*. While #22 is offering a commercial license but is free for personal use, #14 is the only DCFW providing a policy for its adaptation and translation. At least rudimentary *supporting* content or material (e.g., well-worded descriptors) to put a DCFW into action is provided by 20 DCFWs. Tools for the *self-assessment* of DC are either provided or recommended by 17 DCFWs. Most DCFWs claim to be easily adaptable, some of them –especially with teacher focus– can be used as a template for contextualization, but do actually not promote adaptability. 20 out of 25 DCFWs offer resources in terms of *guidance* on how to apply the framework, by either providing a dedicated chapter or section in the main document (#02, #09, #10, #14, #17, #19), online platforms (#06, #08, #16, #22. #23, #24, #25), examples for different types of content, either through descriptors (#04, #13, #15), sample activities (#07,#11, #21), attitudes (#01), or using a model (#12).

Table 5: Applied levels of adaptability for specifying competences by DCFW users.

Level 0	Level 1	Level 2	Level 3
not mentioned	context specific templates for teaching practice	guidelines and scenarios for practical application	specifically designed (flexi-) dimensions

Table 6: Applied levels of AI coverage.

Level 0	Level 1	Level 2	Level 3
not mentioned	illustrative, generic, exemplary	context specific, some related content	embedded, multidimensional

4.2 Adaptability

This section addresses RQ2 (*how do DCFWs provide adaptability for users to specify competences?*). Drawing from criteria for the four hierarchical levels of adaptability (Tab. 5), we discuss details concerning the DCFWs' adaptability for competence specification. In psychology, adaptability can be defined as "the capacity to make appropriate responses to changed or changing situations" (VandenBos, 2007). This definition corresponds with our research focus, investigating to what capacity DCFWs are prepared for technological (AI) shifts. To provide a systematic categorization of how a DCFW is supposed to be used, contextualized, applied or adapted for specifying competences, we mapped them to one of four hierarchical levels, which are defined in the following.

Adaptability Levels.

- In particular, **Level 0** is encompassing DCFWs delivering no results for searching the documents for the terms *adapt**, *flex**, and *change** or from data collected while scanning the DCFWs.
- Those DCFWs mapped to **Level 1** aren't explicitly providing adaptability but can be understood as tangible *templates* for stakeholders with the expertise to use and foremost contextualize them.
- At **Level 2**, DCFWs are characterized by providing supplemental material, supporting contextualization, implementation or adaptation.
- DCFWs at **Level 3** are anticipating technological change by adding specific dimensions for adaptation to new contexts. The DCFW characteristics regarding adaptability are described below.

Adaptability Mapping of DCFWs.

Level 0. Two DCFWs are mapped to this level, #05 (Association of International Certified Professional Accountants, 2019) specifically aims at accountants not necessarily requiring adaptability. While #18 (Dondi et al., 2019) presents 13 skill groups derived from their research, we understand it as a report giving recommendations.

Level 1. Aiming at vocational education/training, #02 is demonstrating "how [it] can be applied in digital skills gap analysis" (Gekara, V, Snell, D, 2019). Targeting the same sector, #11 depicts a subtle granulated structure with well documented components, supported by exemplary activities (Department of Education, Skills and Employment., 2020). #06 and #03 are both adaptions from #09 into a national context, the former (an already updated version) highlighting low-threshold on using digital devices for a broader audience (Nárosy et al., 2022). The latter aims to be a reference for evaluating and developing teachers DCs (INTEF, 2017), supplemented by an online *Digital Competence Portfolio for Teachers*, has also drawn from #07, itself a model to assess and develop pedagogical DC by enabling utilization through well defined sets of competences complemented by a list of typical activities and a progression model (Redecker, 2017). Aiming to describe teachers' DCs, #13 outlines 20 competences structured along four areas of knowledge, offering a "common frame of reference" to enable "inclusive teaching and learning" (Siina et al., 2022). Some DCFWs on this level are similar in presenting a number of competence areas structured along progression levels to enable contextualization. We will briefly outline the key differences. Part of a mandatory cross curricular skills framework, #08 applies descriptors based on predefined *Principles of Progression* (DCF,), supported by learning pathways (Education Wales, UK, 2022). #20 is aiming at professional development and "the actual practice of the profession" (Kelentrić et al., 2017) by delivering a straightforward *template*. While #25 does not promote adaptability, it provides meaningful descriptors and examples (Mediasmarts, 2022). #15 defines identities (i.e., teacher, citizen, connector) (Trujillo Sáez et al., 2020) and can be contextualized but is giving no indication on how to do so.

Level 2. Emphasizing adaptability as an presumed *attitude* for civil servants, #01 is "meant to present governments with a usable set of AI and digital transformation competencies" (Balbo Di Vinadio et al., 2022). To support contextualization and adaptation to different contexts, #09 provides reports and guidelines for implementation (Vuorikari et al., 2022). #10 is presenting a methodical model for *Sustainable Development Goal (SDG) thematic Indicator 4.4.2* supported by pathways for tailoring competence grids to specific needs (Law et al., 2018). #12, supports ap-

plication by illustrating "how the framework could be used by practitioners "using the SAMR model" (Education and Training Foundation, 2019) and a reference guide. In sum, three DCFWs target teacher education and support implementation with extensive supplementary resources; #19 by providing examples of teaching and learning activities (Department of Education. SA, 2019), #17 –updated to version 3– encouraging adaptation and including implementation examples (Butcher, 2018), while #24 delivers online courses –by this, the only DCFW monetising their supplemental material (Foulger et al., 2017). #21 highlights the need for an *adaptive* concept of DC to not become "invalidated by technological innovations", concluding that its implementation therefore must be an *iterative* process (Ministère de l'Éducation et de l'Enseignement supérieur, 2019), supported by examples from different contexts. Targeting IT professionals, #22 provides a platform with 'Help and Online resources' (accessible after registration), including, e.g., skills profiles for industries and jobs (SFIA Foundation, 2021). #23 contains detailed job role descriptions, offering an online portal with tailored training programs (Government of Singapore, 2022). #16 offers "resources that stakeholders can adapt and scale to support their training efforts" (Jacobs et al., 2021), including information on deployment and impact of already realized implementations.

Level 3. Two DCFWs explicitly provide a so-called *flexible dimension*–even though with distinct approaches. Introducing context free descriptors, #04 integrates a '+1' dimension for transversal skills "rarely taught, let alone assessed in formal education contexts" (Adami et al., 2019). While claiming "the placeholder for the 7th context-specific" domain emphasizes that *READY* has been designed with adaptability and flexibility in mind", #14 doesn't elaborate much further on how to do so (European Training Foundation, 2022).

4.3 Coverage of AI Competences

In order to address RQ3 (*how do DCFWs address competences for artificial intelligence (AI), especially generative AI?*), we introduce criteria to evaluate DCFWs by four hierarchical levels of AI coverage (Tab. 6). We then provide further details on the specifics concerning AI coverage for each DCFW.

AI-Coverage Levels.

- DCFWs at **AI Level 0**, do not mention AI at all, manifested by providing no search result, either for searching the documents for terms like *artific**, *generat** and *AI* nor from the data collected while scanning the documents.
- DCWFs mapped to **Level 1** use these terms to illustrate examples of emerging technologies (such as augmented or virtual reality (AR/VR) but do not put them in context with the DCFW itself.
- At **Level 2**, AI is used in a certain context within the DCFW, e.g., in terms of competence descriptors for machine learning or AI ethics, even though application scenarios are not included.
- DCFWs at **Level 3** dedicate a full chapter or section to AI as well as approach this topic in a multidimensional manner.

AI-Coverage Mapping of DCFWs.

Level 0. 52% of DCFWs (#04, #05, #07, #08, #10, #11, #13, #14, #15, #16, #18, #19, #20, #22, #24, #25) do not mention the term AI at all.

Level 1. #02 combines AI with augmented and virtual reality (AR/VR) within a tech indicator system, but does not provide a specific context for the practical application (Gekara, V, Snell, D, 2019). Raising awareness to potential AI applications in education, #03 incorporates AI in context of "digital content creation and programming" (INTEF, 2017). #23 provides job role descriptions for the IT sector, including specific AI-related skills, highlighting the practical applications in specific careers rather than being integrated into a curriculum (Government of Singapore, 2022).

Level 2. The **only** DCFW using the term *generative AI*, #12 is situating AI under the competence area "Subject and Industry Specific Teaching", focusing on professional development. While AI is mentioned in various activities, the descriptions remain general, such as "using AI (AR, VR)" (Education and Training Foundation, 2019). Strongly based on #09, #06 does not yet fully integrate all of the original models latest update (introducing AI competences) but added a low-threshold online module on the basic impacts of AI. #21 categorizes AI under "developing and mobilizing technological skills", highlighting the importance of a general understanding of AI, also in context of "developing critical thinking about the use of digital technologies" (Ministère de l'Éducation et de l'Enseignement supérieur, 2019).

Level 3. #01 focuses on "the major AI and digital transformation competencies needed in the public sector" (Balbo Di Vinadio et al., 2022) –the only DCFW we could identify to do so. With Version 2.2. #09 introduced a section addressing AI, focusing on citizens interacting **with** AI systems, "rather than focusing on the knowledge about Artificial Intelligence per se" (Vuorikari et al., 2022), demonstrating its commitment to human-centered considerations including AI-assisted and AI-automated decision making (Eigner and Händler, 2024), as well as addressing

ethical impacts. #17 dedicates a chapter exploring AI and its role in assistive technologies, highlighting the impact on accessibility "made possible by advances in 'machine learning' and 'deep learning' algorithms" (Butcher, 2018), raising awareness on how AI can be used to support students with disabilities. with statements like "AI facilitates|can assist|enables ...", it exemplifies activities for the competence area 'Application of Digital Skills'.

4.4 Mapping of Adaptability and AI Coverage

Fig. 3 summarizes the key findings from the systematic mapping study driven by the question to which extent established DCFWs are suitable for specifying competences for generative AI. In particular, it illustrates a two-dimensional matrix correlating the levels of AI competence coverage (*y-axis*) and the levels of adaptability (*x-axis*). The resulting grid is divided into four quadrants (Q1–4), in which the analyzed DCFWs are located in terms of bubbles indicating their quantified distribution.

- DCFWs clustered in quadrant **Q1** provide some adaptability but do not address AI at all or only marginally. Aiming mostly at teachers and trainers, focusing more on contextualization and practice transfer than on adaptability, they may equip teachers with the DC to adapt to some extent to new technology when given the necessary resources to do so.
- DCFWs located in **Q2** show strong adaptability but still refer to AI on a basic level. They address different target groups and cover every sector except accountancy and financial services.
- Only one DCFW is situated in **Q3** by providing the same basic adaptability, but fulfilling the criteria for *AI level 1*.
- **Q4** unites the *star pupils* with strong adaptability by either providing tangible material for practical application and adaptability to new contexts or having a specifically designed dimension to accommodate new competence fields emerging from technological shifts. Nevertheless, out of 25 analyzed DCFWs, there is just a single one using the term 'generative AI' in a few of their competence descriptors (Education and Training Foundation, 2019).

5 DISCUSSION

In this section, we reflect on limitations of the applied approach (Section 5.1), discuss observed challenges (Section 5.2), and illustrate the utility of our findings by example (Section 5.3).

5.1 Limitations

As illustrated in Section 3, our analysis follows a systematic mapping approach driven by the stated research questions. However, throughout our analysis, we have identified several aspects worthy of further elaboration. For instance, other DCFWs (cross-)referenced by the selected DCFWs could by investigated in detail, especially the ones deriving from #09, of which a number of adaptations are already documented (Vuorikari et al., 2022). Due to the purpose of this study, DCFWs published by individual organizations (e.g., universities) were deliberately not considered, whereby this could be a promising research avenue. In addition, most DCFWs analyzed originate from '*developed*' countries, which leaves a significant gap especially concerning Asia and Latin-America, further aggravated by limited accessibility through language. Due to the high diversity of target groups and aims, e.g., encompassing K-12, the vocational sector, higher education as well as individual citizens, the mapping required the application of coarse and generalizing categories. A detailed investigation of domain-specific circumstances would be useful for future work.

5.2 Challenges

Driven by the question how far the characteristics of DCFWs can be broken down to simple variables while still giving valuable information, we we have observed several challenges in the course of analyzing the DCFWs. As outlined in Section 3, one challenge was to actually identify established DCFWs. Since *DigComp* (#09) was some kind of anchor while still planning this research, we were lucky finding it accompanied with a multitude of literature preceding and ultimately substantiating the DCFWs, and pointing us to the *UNESCO-UNEVOC* database serving as source for backward snowballing. Based on analyses of the corresponding DCFWs as well as further literature (see Section 2), it becomes manifest that there is no terminological consistency concerning the terms *digital literacy* and *digital competence*, as was already observed by (Mattar et al., 2022) and (Ferrari et al., 2012). Also, related research is pointing out that defining DC is depending on multiple aspects such as

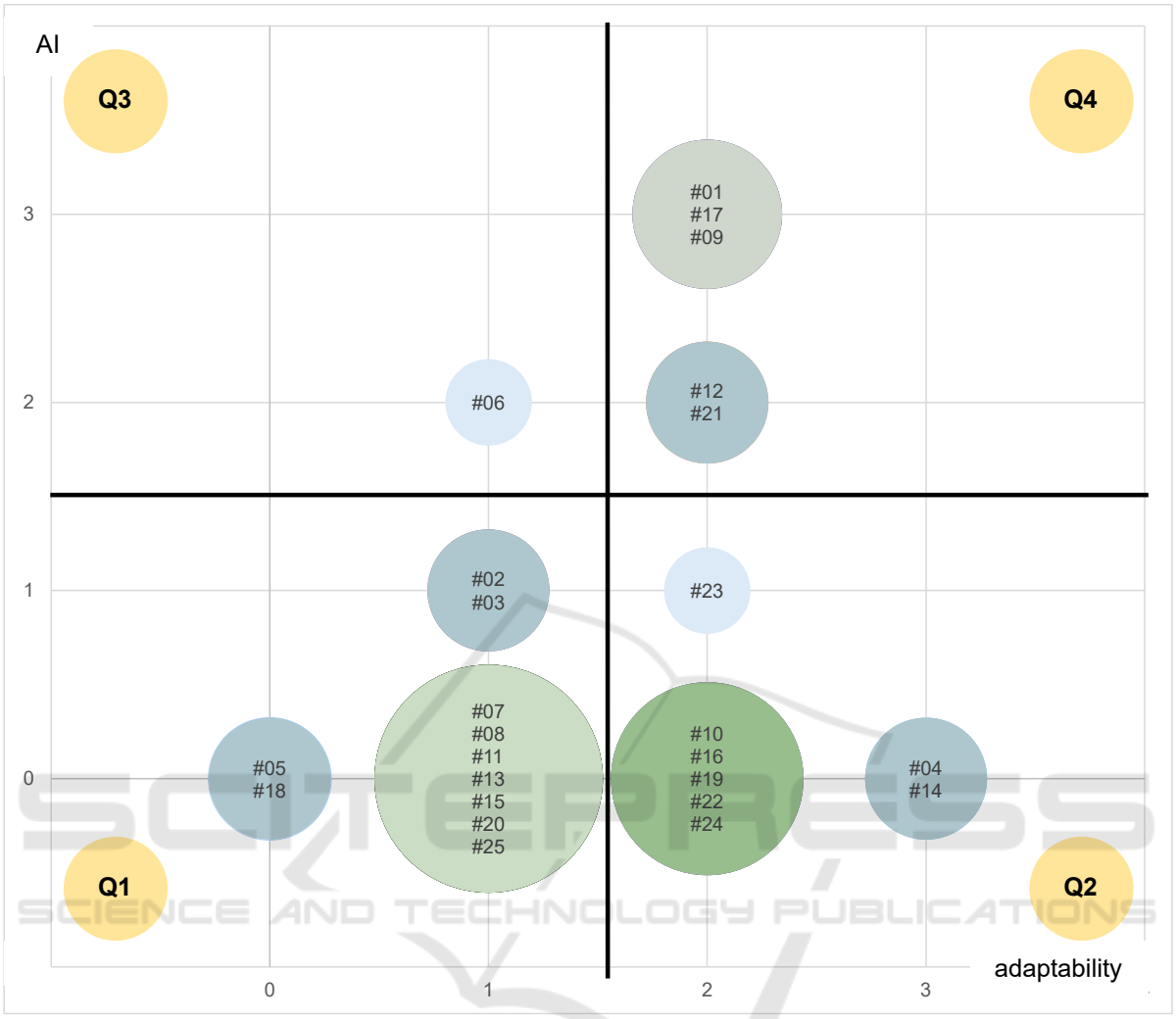

Figure 3: Matrix classifying digital competence frameworks (DCFWs) according to their levels (0–3) of AI coverage (*vertical*) and adaptability (*horizontal*) into four quadrants (Q1–4).

context, purpose and aim, and therefore to be understood as *fluent concept*. There are obviously more aspects which still need to be explored more thoroughly. Furthermore during data collection, we gathered more structural data than we could address in this paper, like a comparison of terminological consistency, its purpose in context with its aims or details on the provided means of (self-)assessment, which will be addressed in future research.

5.3 Practical Utility

This paper's purpose was to systematically analyze and categorize established DCFWs, with emphasis on AI coverage and adaptability for competence specification. The resulting overview condensed in the matrix in Fig. 3, can be utilized by practitioners to select, evaluate, and apply DCFWs, which is illustrated by the following exemplary application scenarios.

- First, consider teaching staff at a university aiming to choose a DCFW suitable for defining AI-related learning objectives for a course and subsequently assessing students' performances against these objectives. In this case, DCFWs #09 and #17 would be suitable candidates.
- Then, imagine an HR expert in a company aiming to determine the AI-related competences required for project staffing. Focusing on vocational education and training and assigned to AI level 2, e.g., #12 could provide the necessary means for orientation, while other DCFWs with the same target sector do not include AI competences.

6 CONCLUSION

This paper presents the results of a systematic analysis of established digital competence frameworks (DCFWs) with focus on how the DCFWs address AI competences and provide adaptability for competence specification due to challenges of rapid technological development. A key contribution of this paper is the development and application of criteria for classifying DCFWs into hierarchical levels regarding adaptability and coverage of AI competences. Resulting from applying these criteria, we present a matrix (Fig. 3) illustrating the DCFWs distribution according to their mapped levels for both aspects, aiming to support stakeholders in choosing the most suitable DCFW for their specific application purposes. This matrix can be utilized by a broad audience, including educators, VET and labour market experts, HR and IT professionals, management personnel, or researchers. The most significant findings from analyzing DCFWs' **adaptability** are that only few DCFWs can be mapped to level 2 or 3, highlighting the need for a clearer distinction between contextualization and adaptability. Concerning **AI coverage**, most surprising was that just **one** DCFW actually uses the term *generative AI* in its competence descriptors, while 52% of the analyzed DCFWs do not mention AI at all. Furthermore AI is often placed in the field of informatics and programming, but rarely regarded multi-dimensional. Following up on if and how these DCFWS will respond to the challenges inherent to generative AI and large language models (LLMs) and its impact on education, labour and society in general, could represent interesting research directions. Our work can be seen as a first exploration of DCFWs regarding this rapidly evolving field of generative AI. The resulting overview provides a first practical orientation and forms the basis for further research in terms of in-depth analyses, e.g., taking a closer look at how AI competences are addressed by DCFWs located in Q4, or conceptual work, e.g., developing a DCFW tailored to the challenges posed by generative AI.

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