Journal of Business Economics (2025) 95:553–586
https://doi.org/10.1007/s11573-024-01212-9

ORIGINAL PAPER

Improving the use of public e-services through explainability

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Accepted: 8 October 2024 / Published online: 29 October 2024

Abstract

Despite an omnipresent call for public e-services, the potential of digitalization in the public sector is still untapped. A promising means to increase the use of public e-services may be explainability. In this study, we follow the Design Science Research methodology to propose and evaluate design principles for explainability of public e-services. We instantiate the design principles in cooperation with the German Federal Statistical Office using the example of its public e-service Personal Inflation Calculator. We evaluate the design principles in a user study with 226 users and an expert survey with 17 public sector digitalization experts. Results confirm the design principles' utility and applicability. Furthermore, we investigate the impact of explainability on the use of public e-services. In a randomized online experiment with 204 citizens, we demonstrate the positive impact of explainability of public e-services on perceived ease of use, perceived usefulness, self-efficacy, trust, and intention to use. With our design principles, we provide applicable and prescriptive knowledge on explainability of public e-services. Our findings on the impact of explainability on the use of public e-services contribute to the understanding of the role of explainability in digitizing the public sector.

Keywords Explainable e-services · Public e-services · Public sector · Design science research · Design principles

JEL Classification M00

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1 Introduction

Across the globe, governments strive for the transformation of public organizations to adapt to a changing environment and to address societal changes (Lindgren and van Veenstra 2018). Transformational objectives include the facilitation of IT to create public value (Lindgren and van Veenstra 2018; Stoker 2006) and the increase of governments' responsiveness and openness (Bannister and Connolly 2014; Lindgren and van Veenstra 2018). Digital government is a driver of this transformation (Lindgren and van Veenstra 2018) and is often realized through the digitalization of public services (Lindgren and Jansson 2013). Numerous initiatives are underway around the world to digitize public services to so-called public e-services (OECD 2023). Over the past 20 years, Europe's public administration has seen a significant digital leap: from 20% of services online in 2003 to 84% in 2023, enabling full electronic case handling (Dogger 2023). The European Union, for example, plans to make all major public services online available to citizens and businesses by 2030 (European Commission 2022). Germany alone has the potential to save its citizens 84 million hours of their time (Stern et al. 2018) and businesses 50% of their costs for public sector interaction each year (Daub et al. 2020). Further, civil servants could save about 60% of their working time (Daub et al. 2020), which is critical given the skills shortage in the public sector (Chinn et al. 2020).

However, in many countries, both citizens and civil servants are currently dissatisfied with the state of digitalization of public services (Chinn et al. 2020; OECD 2022). A possible reason why public e-services have not yet achieved the desired success is that the transition from traditional citizen services with personal contact to digital (self-)services is still too challenging for many users (Distel 2020; Jarke 2021). Citizens, who are lay users, often do not understand public e-services (Jarke 2021; Madsen et al. 2019) and miss explanations (Madsen et al. 2019), especially since public e-services are often not user-centric and do not reach citizens at their level of knowledge (Heuberger and Schwab 2021).

Studies on lay user interaction with e-services in other domains demonstrate the potential of explanations to improve user interaction by increasing, for instance, usefulness, ease of use (e.g., Conati et al. 2021; Hamm et al. 2021), and trust (Bayer et al. 2021). The unique characteristics of the public sector domain offer substantial potential for explainability due to the complexity of service delivery (Lindquist 2022), the high demand for accountability and transparency in public services (Harrison and Sayogo 2014), and the challenges in serving the interests of all citizens at once (Lindgren and Jansson 2013). Although digital technologies have advanced rapidly, research on their application in the public sector is relatively sparse (Joukhadar et al. 2023). The rapid advancement of technology and the focus of policymakers on automation and digital self-service necessitate scholarly investigation into how digitalization affects the interactions between citizens and public authorities in the delivery of public services (Lindgren et al. 2019). A relevant, but so far mostly neglected, perspective to investigate the use of public e-services is explainability.

Therefore, we aim to explore the role of explainability for the use of public e-services. To this end, we follow the Design Science Research (DSR)

methodology (Hevner et al. 2004; Peffers et al. 2007) to develop and evaluate design principles for the explainability of public e-services. We conduct two iterative design cycles to develop design principles (Gregor et al. 2020; vom Brocke et al. 2020). Moreover, we instantiate the design principles in cooperation with the German Federal Statistical Office using the example of its public e-service Personal Inflation Calculator. We evaluate the utility and applicability of the design principles from users' perspectives and with public sector digitalization experts. Furthermore, we investigate the impact of explainability on perceived ease of use, perceived usefulness, self-efficacy, intention to use, and trust in a randomized online experiment with 204 citizens. The results of our evaluation demonstrate the utility and applicability of the proposed design principles. The results of our online experiment reveal a positive impact of explainability on perceived ease of use, perceived usefulness, self-efficacy, intention to use, and trust.

Our theoretical contribution is twofold. First, we establish design principles for the explainability of public e-services, which provides applicable and prescriptive knowledge on the explainability of public e-services, which can be reused and enhanced in future research (Gregor et al. 2020; vom Brocke et al. 2020). Beyond our instantiation in cooperation with the German Federal Statistical Office, we expect that the design principles are particularly applicable to public e-services in stage 2 (interaction), which allow users to interact with government agency databases by offering enhanced search, filtering, and calculation services, such as managing debt or accessing government subsidies (Goldkuhl and Persson 2006; Jansen and Ølnes 2016) (cf. Section 2.2). Second, our insights regarding the impact of explanations on the use of public e-services contribute to the understanding of the role of explainability in digitizing the public sector. First and foremost, our findings demonstrate the positive impact of explanations on the adoption of and trust in public e-services. From a practical point of view, our design principles can be implemented to develop explainable public e-services or to introduce explainability into existing ones. Second, our insights on the impact of explainability on public value creation serve public sector organizations to anticipate the impact of explainability when implementing public e-services.

The remainder of this paper is structured as follows. In Sect. 2, we provide an overview of related work. Afterwards, in Sect. 3, we present the methodology. In Sect. 4, we develop design principles for the explainability of public e-services. Section 5 is dedicated to the demonstration and evaluation of the design principles and the investigation of the impact of explainability on the use of public e-services, followed by implications for theory and practice in Sect. 6. Section 7 concludes with an outlook for further research and reflects on limitations.

2 Related work

2.1 Explainable information systems

This section is primarily concerned with delving deeper into explainable IS and specifying the anchoring of our work. While there are several related concepts

to explainability in information systems (IS) research (Miller 2019), we focus on explanations for lay users, such as citizens.

In IS research, explanations can be defined as causes of a specific event (Humphreys 1989). While global explanations explain the general functioning of an underlying IS, local explanations are more often employed for lay users, as they outline the reasons for a specific outcome of an IS (Adadi and Berrada 2018). For example, when using a public e-service to apply for a financial benefit, citizens may be more interested in the reasons for their individual rejection or approval than in the overall most relevant criteria for benefit allocation. For lay users, pragmatic explanations are particularly promising, as they connect theory and fact with the context (Salmon 1998; van Fraassen 1980). Pragmatic explanations can be characterized by four attributes (Miller 2019): First, they are contrastive. They explain the respective outcome of an IS in relation to another perceivable one that did not occur, similarly to how lay users interact who usually do not refer to the causes of an event per se, but to the causes in relation to another potential event (Miller 2019). Second, they are selected. Pragmatic explanations almost never encompass the complete cause chain of an outcome. Instead, an explanation includes a limited number of selected causes—partially—leading to the outcome of an IS (Miller 2019). For example, when receiving a rejection for a financial benefit through public e-services, citizens might be most interested in the decisive factors of their rejection instead of being also presented all criteria they have successfully met. Third, pragmatic explanations are not probability centered. While the exclusive use of statistical generalization is unsatisfying from a user perspective, most lay users instead care about the underlying causes (Miller 2019). Fourth, pragmatic explanations are social and usually embedded in an interaction (Miller 2019).

Local and pragmatic explanations for lay users are closely related to personalized explanations, which reveal causal relationships about a certain topic based on individual information and task-related interest in transparency (Meske et al. 2022). In the IS literature, several quality criteria for personalized explanations have emerged (Meske et al. 2022; Schneider and Handali 2019): *Comprehensibility* describes the extent to which the explanations are helpful to fulfill a certain task. *Effort* refers to how many resources are required to understand the explanations. *Explanatory power* indicates the scope of questions that the explanations can answer. *Fairness* means that the explanations are equally good for all users. *Fidelity* describes that the explanations represent the underlying IS well. *Generalizability* refers to the scope of IS that can be explained. *Interpretability* describes whether users understand the explanations. *Plausibility* indicates whether users accept the explanations. Finally, *privacy* describes that the explanations do not allow any conclusions to be drawn about the person and that no data is stored. While these criteria represent overarching quality criteria, researchers emphasize the need to adapt and weight them in an application context (Meske et al. 2022; Schneider and Handali 2019).

Building on these concepts of explanations for lay users, we follow Miller's (2019) and Meske et al.'s (2022) call to determine what constitutes appropriate explanations for a specific target group, in our case, users of public e-services.

2.2 E-services in the public sector

A public e-service "means usually that an external user (a citizen) interacts through a user interface of a public IT system based on web technology" (Goldkuhl and Persson 2006, p. 6). In the literature, stage models are commonly used to refine the concept of public e-services (Lind and Goldkuhl 2008). Although there are variations, the core characteristics of public e-services encompass a series of four stages (cf. Goldkuhl and Persson 2006; Jansen and Ølnes 2016; Lee 2010). Stage 1 (presence/information) primarily focuses on presenting static content, such as publications and details about the agency's services, while stage 2 (interaction) provides users with limited interaction possibilities within government agency databases, offering improved search, filtering, and calculation services, such as managing debts or accessing government subsidies (Goldkuhl and Persson 2006). Stage 3 (transaction) involves the initiation and tracking of agency-specific services, such as online tax declarations, and stage 4 (transformation/integration) focuses on integrating services among government agencies to achieve a one-stop government approach (Goldkuhl and Persson 2006). According to Jansen and Ølnes (2016), public e-services can be distinguished along three key dimensions: the purpose of an interaction from the provider's perspective, the content and structure of the interaction, and the impact on the receiver. To illustrate, for public e-services in stage 2, such as a personal inflation calculator, the purpose of interaction goes beyond merely providing general information to initiating a well-defined data handling process, such as completing an electronic form (Jansen and Ølnes 2016). The content and structure of the interaction are dynamic, while not involving the formalized exchange of structured information required by regulations (Jansen and Ølnes 2016). The impact on the receiver in stage 2 involves a change in the user's status, such as updating or obtaining personal information, but does not imply contractual relationships or legal consequences (Jansen and Ølnes 2016). In contrast, for public e-services in stage 3, such as services for the calculation and submission of the tax return, the purpose of the interaction is to perform a legally regulated task. Such public e-services involve a formalized exchange of structured information and result in establishing a contractual relationship (Jansen and Ølnes 2016). As the impact of such services on the recipients is more critical, they often feature secure identification (Goldkuhl and Persson 2006).

Governments are transitioning from traditional public service delivery to public e-services across all four stages to meet user demands and to reduce costs. The success of this transition depends on citizens' adoption of these services, which requires the provision of high-quality public e-services (Kohlborn 2014). Given that many public services have a direct impact on citizens, it is crucial to understand how they perceive and evaluate the performance of these services (Zhang et al. 2022). To this end, the literature provides quality criteria which align with the stage model above. Building on the works of Papadomichelaki and Mentzas (2012), Kohlborn (2014), and Jansen and Ølnes (2004), Jansen and Ølnes (2016) provide a framework for assessing the quality of public e-services from users' perspective. The first dimension of this framework evaluates how users perceive usability and functionality, including indicators for stage 2 (interaction) such as ease of use, personalization,

and usefulness. The second dimension examines the trustworthiness of the service provision, encompassing indicators like privacy, security, and confidentiality. The third dimension assesses content quality, considering indicators such as correctness, completeness, and functionality. The fourth dimension addresses technical performance with indicators such as stability, capacity, robustness, and reliability. The fifth dimension focuses on organizational capabilities and citizen support, including (vertical) integration of processes or function.

2.3 Barriers to the adoption of public e-services

Despite the high ambitions and great progress of many public e-services, the full potential of digitalization remains untapped (Alvarenga et al. 2020). Many government agencies encounter substantial challenges in increasing adoption of public e-services as the actual usage rate significantly lags behind the deployment rate (Zhang and Kimathi 2022). Against this background, literature examines the barriers to the adoption of public e-services. In a comprehensive literature review, Distel and Ogonek (2016) identified six overarching categories of barriers from a citizens' perspective: technological, socioeconomic, communication, cultural, individual, and service-related barriers. Technological barriers encompass a range of issues, with the primary concern being perceived security and privacy risks. Socioeconomic barriers involve disparities in access to technology based on factors such as age or education. Communication barriers include obstacles arising from inadequate communication, such as lack of awareness, and are consistently noted as significant impediments to e-government adoption. Cultural barriers encompass challenges influenced by an individual's cultural background, including norms, traditions, and levels of trust in governmental institutions. Individual barriers pertain to personal preferences, attitudes, and constraints such as time limitations, perceived utility, and habitual behaviors. Service-related barriers encompass the complexity of specific procedures and the requirement for direct interaction with government personnel. Citizens face a tremendous shift from personal consultation with human counterparts to digital interaction with public e-services that often lack consultation as a core element of public service provision in practice (Distel 2020). A study by Madsen et al. (2019) shows that despite mandatory use of e-services, citizens commonly still need to interact personally with public administrations, among others, due to information-related problems. This includes the need for explanations.

2.4 Role of explainability for digitizing public services

The potential of explainability for successful digitization of public services in overcoming the adoption barriers of public e-services is underscored by existing insights on the positive impact of explainability on user interaction with other e-services. Prior studies in various domains have demonstrated that providing explanations positively influences usefulness, ease of use, and intention to use when interacting with e-services (e.g., Conati et al. 2021; Hamm et al. 2021). These factors are vital drivers for overcoming individual barriers for the use of public e-services. Further,

quality improvements to e-services with the potential to increase citizen satisfaction are expected to equally improve civil servant satisfaction due to a rising perception of strengthened value provision to citizens and, thus, help to overcome service-related barriers (Heintzman and Marson 2005). Finally, several studies have shown a positive influence of explanations on trust (e.g., Bayer et al. 2021; Conati et al. 2021), which could be expanded to overcome the cultural barriers for use of public e-services.

Initial research has been conducted to explore explainability in the context of digitizing the public sector. Existing research focuses on the use of explainability to improve processes and develop decision support systems for domain experts. For example, Mehdiyev et al. (2021) examine the potential of e-services to support tax authority processes and find that explanations help auditors to select audit cases more precisely and increase their trust in the system. Maltbie et al. (2021) investigate explainability in a public sector case study in the domain of predicting combined sewer overflows. The authors evaluate the clarity, validity, and depth of the generated explanations and conclude that complex explanations can provide domain experts with novel insights that may challenge their existing expectations. Asatiani et al. (2021) assess how a Danish agency, dedicated to enhancing business growth and employing AI for operational improvements, tackles the challenge of explaining AI models' inscrutability when faced with the need for explainability in a government unit. To the best of our knowledge, explainability has not yet been studied for public e-services that expand beyond internal processes (Mehdiyev et al. 2021).

Existing research does not yet provide a comprehensive understanding of what constitutes effective explanations in the context of public e-services. IS research holds promise as a source of inspiration for explainable e-services—local, pragmatic, personalized explanations serve as a starting point for designing explainable public e-services. Researchers emphasize that explanations need to address the specific needs of users (e.g., Schröppel and Förster 2024; Schneider and Handali 2019). To illustrate, research demonstrates the superiority of user-tailored explanations compared to universal explanations (Schröppel and Förster 2024). Our study builds on these insights to develop design principles for explainability targeted to users of public e-services.

3 Methodology

We followed the DSR process to develop and evaluate design principles for explainability of public e-services (Peffers et al. 2007). DSR enables scholars to create knowledge that is transferable to real-world scenarios (vom Brocke et al. 2020; Gregor and Hevner 2013; Gregor et al. 2020). Design principles represent design knowledge in form of operational principles and can be transferred to real-life applications (Gregor and Hevner 2013). Our DSR process includes six activities in two design cycles (cf. Fig. 1). In line with Peffers et al. (2007), we derived design requirements which represent the goodness criteria and support the evaluation of the designed solution (e.g., vom Brocke et al. 2020). We developed design principles which address the design requirements (vom Brocke et al. 2020).

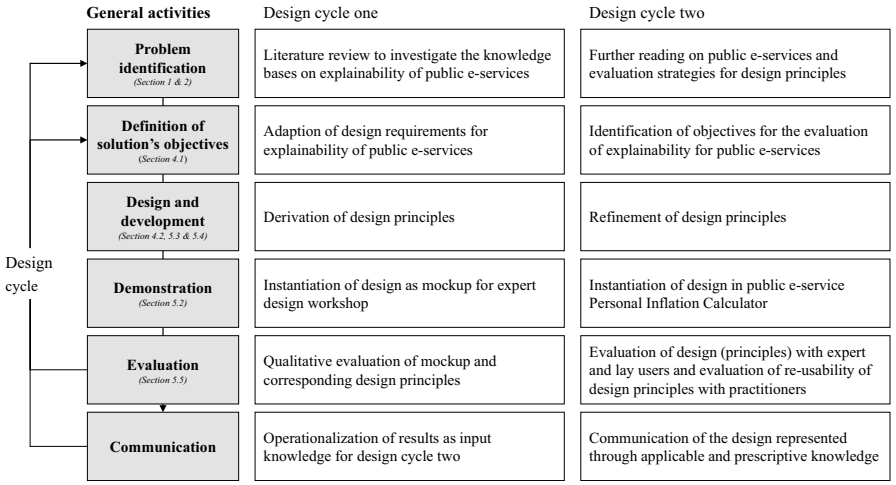

Fig. 1 DSR process adapted from Peffers et al. (2007)

The first design cycle started with a literature review. We found that existing research had not yet adequately addressed the explainability of public e-services (cf. Sects. 1 & 2). We identified generic design requirements based on quality criteria for public e-services as well as quality criteria for personalized explanations (cf. Sect. 4.1). We developed design principles (cf. Sects. 4.2 & 5.3) and implemented a mockup artifact that was qualitatively evaluated in an expert design workshop. We operationalized these findings for the second design cycle.

The second design cycle started with further investigation of explainability of public e-services (cf. Sect. 2) and exploration of evaluation strategies. Moreover, we revised the design principles based on the expert design workshop of the previous design cycle (cf. Sects. 4.2 & 5.4). The revised design was implemented as a web-based prototype (cf. Sect. 5.2). The evaluation in this cycle was threefold. First, we conducted a qualitative user study with 226 users to evaluate each design principle. Second, we evaluated the utility and applicability of the design principles by consulting 17 practitioners with diverse professional experience in the digitalization of the public sector. Third, to evaluate the impact of explainability of public e-services, we conducted a randomized online experiment with 204 citizens in a treatment group and a control group (cf. Sect. 5.5).

Throughout this paper, we communicate the resulting design knowledge.

4 Design and development

We developed design requirements and design principles for explainability of public e-services, following vom Brocke et al. (2020). Hereby, the term explainability refers to individual information that reveals the causal relationships about the outcome of the public e-service.

4.1 Derivation of design requirements

Design requirements represent the goodness criteria and part of the problem space (vom Brocke et al. 2020). We derived design requirements based on quality criteria for personalized explanations, applicable to both public and private e-services (Meske et al. 2022; Schneider and Handali 2019), and we refined them based on quality criteria specific to public e-services (Jansen and Ølnes 2016). Regarding quality criteria for explanations that target both, public and private e-services, we focused on fairness, fidelity, effort, plausibility, comprehensibility, and interpretability by Meske et al. (2022). We disregarded the quality criteria explanatory power and generalizability because they depend on the particular e-service. To illustrate, explanations only need to explain one underlying IS. We also disregarded privacy, which should be considered in the underlying IT system of the respective public institution. Regarding the quality criteria for public e-services, we focused on criteria introduced by Jansen and Ølnes (2016) in the context of public e-services: usability and functionality, content quality, and technical performance. We disregarded trustworthiness, which focuses on privacy concerns, and organizational capabilities, as those criteria should be considered in the underlying IT system of the respective public institution and, thus, apply to private e-services but not to public e-services (Jansen and Ølnes 2016). In the following, we present the resulting design requirements for public e-services, which can also be applied to private e-services in future research.

First, a public e-service should be easy to use (Jansen and Ølnes 2016), meaning that a person believes that using a particular e-service would be free of effort (Davis 1989) and that the e-service is easy to interact with (Papadomichelaki and Mentzas 2012). This design requirement applies to both, public e-services (e.g., e-Government portals) and private e-services (e.g., web-shops), with developers having an interest in increasing e-service usage by keeping the barriers to entry for users low. This is particularly relevant for public e-services with a diverse user group with heterogeneous educational attainments, prior knowledge, and demographics. Studies in different contexts and countries show that citizens only use public e-services continuously if they are easy to use (Distel 2020). In this vein, it is also important that explanations are understandable and can be interpreted with little effort (Meske et al. 2022). If explanations are too complex humans are cognitively overloaded (Asher et al. 2021). Thus, we establish the first design requirement: *explainability should contribute to the ease of use of the public e-service.*

Second, public e-services must be useful for citizens (Jansen and Ølnes 2016), which means that a person believes that using a particular service will improve their performance (Davis 1989). Again, this design requirement applies to both, public and private e-services. The usefulness of an e-service influences the perceived value and use intentions of citizens (El-Haddadeh et al. 2019; Hamid et al. 2016). Thus, citizens will only use the respective e-services—whether it is a public transformation e-service or a private streaming service—if they consider it to be useful. These usage rates are particularly important for the public sector, given its skills shortage (Chinn et al. 2020). Therefore, it is especially important that the e-service is useful for all citizens (Li and Shang 2020). This is in line with quality criteria for

personalized explanations, which should have the same quality for all users (Meske et al. 2022). In addition, explanations must be interpretable, meaning that they are understandable for humans. This is linked to usefulness, as only explanations that citizens understand are useful to them (Hoffmann et al. 2019). Thus, we establish the second design requirement: *explainability should contribute to the usefulness of the public e-service.*

Third, public e-services need to be reliable and correct (Jansen and Ølnes 2016). Only if citizens have confidence in the reliability and integrity of an e-service will they trust it (Belanger et al. 2002) and potentially use it (Carter and Bélanger 2005). This design requirement applies to all trust-based e-services, particularly those that deal with sensitive information such as public social e-services or private banking e-services. It is particularly applicable to public e-services given the amount of sensitive information involved in state-citizen interactions (Cavanillas et al. 2016) and the high demand for accountability and transparency in public services (Harrison and Sayogo 2014). The requirement for trust is closely related to the quality criteria plausibility and fidelity for explanations. Users are likely to accept plausible explanations, which provide a high degree of fidelity regarding the input–output mapping of the IS (Meske et al. 2022; Schneider and Handali 2019). This translates into explanations that increase the trust in the public e-service. Thus, we establish the third design requirement: *explainability should increase the trust in the public e-service.*

Fourth, the content of public e-services needs to be of sufficient quality with respect to relevance, correctness, and functionality (Jansen and Ølnes 2016). This implies that the content of the e-service is appropriate for citizens and addresses their needs, enabling them to benefit from it (Distel and Lindgren 2023; Li and Shang 2020). This last design requirement targets both, public and private e-services to incentivize use. For example, an incomprehensible public health service can be just as discouraging to citizens as much as a confusing food delivery service. Users will thus shay away from it, if use is not mandatory, and may prefer to use other forms of communication. Particularly in public e-services, citizens as lay users often perceive digital (self-)services as too challenging (Distel 2020; Jarke 2021). Yet, in contrast to private e-services, the use of public services is often not voluntary but rather necessary—citizens cannot simply change the provider of the e-service, so they have to rely on the appropriate quality of e-services. In line with the need for sufficient quality, the quality criterium comprehensibility for personalized explanations refers to the capacity of an explanation to aid a user in performing a task (Meske et al. 2022). Comprehensible explanations are meant to help citizens benefit from the public e-service, thereby enhancing their belief in their ability to carry out specific actions, i.e., self-efficacy. Thus, we establish the fourth design requirement: *explainability for public e-services should enhance citizens' self-efficacy.*

4.2 Derivation of design principles

Design principles are part of the solution space and address the design requirements (vom Brocke et al. 2020). They are used to communicate design knowledge in an

accessible format with different stakeholders (Gregor et al. 2020). With our design principles (cf., Fig. 2), we aim to improve the use of public e-services for citizens. We address public organizations and their developers to instantiate our design principles in public e-services. IS and (e-)government researchers can reflect on and capture the design knowledge. In the following, we present our design principles following Gregor et al. (2020).

Provide explanations that are understandable without prior knowledge (DP1): The aim of the first design principle is for public organizations to provide explanations in public e-services that are easy to use for citizens. This design principle is specific to public e-services, which have two distinguishing characteristics, namely a broad lay user group as well as primarily involuntary use. First, citizens are characterized by mixed expertise and background knowledge, therefore, neither technical nor domain knowledge can be assumed. In the context of explainability, this is often referred to as lay users (Wachter et al. 2017). For lay users, explanations that require technical knowledge cannot be used or can only be used to a limited extent (Wachter et al. 2017). Second, many interactions with a public organization through public e-services are involuntary, including either compulsory claims that do not involve choice (e.g., taxation) or monopolized services (e.g., social services) (Lindgren 2013). Thus, citizens cannot 'pick and choose' among e-services, but need to interact with a respective e-service (Lindgren 2013), which must therefore be adequately

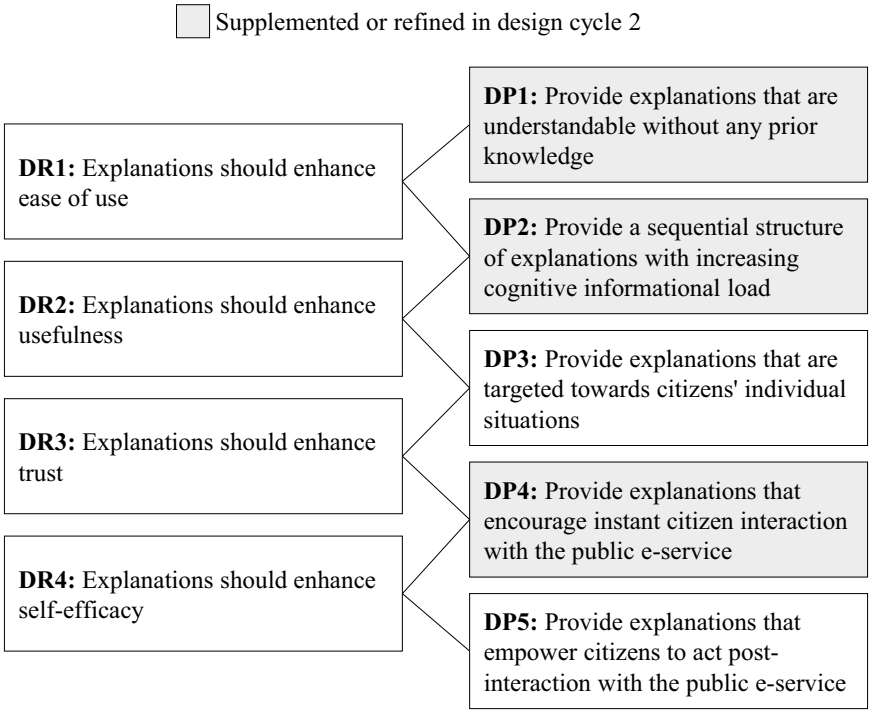

Fig. 2 Overview of the design requirements and the design principles

understandable. Thus, we establish that explanations must be understandable without prior knowledge.

Provide a sequential structure of explanations with increasing cognitive informational load (DP2): The aim of the second design principle is for public organizations to provide explanations in public e-services that are useful and easy to use for citizens. Again, this design principle is specific to public e-services due to two main attributes: First, public organizations interact with diverse user groups. Since citizens have a particular high degree of heterogeneous educational attainments, prior knowledge, and demographics, there is a fine line between information underflow and information overload from a user perspective (Chromik and Butz 2021; Millecamp et al. 2019). While an explanation may be insufficient for one citizen, it may overstrain another (Chromik and Butz 2021). Second, unlike private organizations, public organizations adhere to the public ethos with public e-services intended to work equally for all citizens (Lindgren 2013). For example, a bank may differentiate between customer segments, or a digital web shop may use collected information about a user's past purchases in order to make them personalized offers. In contrast, public organizations need to ensure that all citizens receive the same information. To still acknowledge that some citizens are more interested in further other (more complex) information than others, explanations should—next to a basic comprehensible explanation for all users—comprise hierarchical functionalities that allow for follow-ups on initial explanations (Springer and Whittaker 2019). Thus, we establish that explanations must provide a sequential structure of explanations with increasing cognitive informational load.

Provide explanations that are targeted toward citizens' individual situations (DP3): The aim of the third design principle is for public organizations to provide explanations in public e-services that are useful and increase trust for citizens. This design principle applies to both, public and private e-services, and is anchored in research on explainability that distinguishes global and local explanations (Adadi and Berrada 2018). Local explanations focus on explaining a particular outcome, such as the most essential criteria for a certain outcome of a public e-service. Such local explanations can increase trust in an e-service as they are directly targeted to an individual situation. Moreover, given citizens' preference for effective and efficient administrative interactions (Heuberger and Schwab 2021), explanations should offer straightforward guidance on citizens' most pressing questions: how a particular outcome has been achieved for their individual matter. DSR in related domains has identified similar design requirements, for instance, the need for "case-based, contextual information" in hate speech (Meske and Bunde 2023, p. 751) and fraud detection (Cirqueira et al. 2021). Thus, we establish that explanations must be targeted towards citizens' individual situations.

Provide explanations that encourage instant citizen interaction with the public e-service (DP4): The aim of the fourth design principle is for public organizations to provide explanations in public e-services that increase trust and self-efficacy for citizens. Citizens use public e-services to clarify their matters, yet often bemoan the lack of personal consultation (Distel 2020). This starting point equally applies to many private e-services, where most interaction occurs digitally with difficulty to get in touch with a human counterpart. Due to a lacking human counterpart in public

e-services, users need a high degree of self-efficacy in interaction with the system to adequately clarify their matter without third-party support. One conceivable solution is the encouragement of interactive system exploration (Cheng et al. 2019). Interactive explanations can improve both, self-reported and objective user comprehension (Cheng et al. 2019). DSR in related domains has identified similar design requirements, for instance, the relevance to "initiate case-related actions" in hate speech (Meske and Bunde 2023, p. 751) and the need for "interactive explanations" in fraud detection (Cirqueira et al. 2021, p. 7). Thus, the more users are encouraged to explore, the more they feel confident in their abilities to understand and master interactions with public e-services. Furthermore, successful interaction also leads to increased trust in the public sector (Fledderus 2018). Thus, we establish that explanations must encourage instant user interaction with the e-service.

Provide explanations that empower citizens to act post-interaction with the public e-service (DP5): The aim of the fifth design principle is for public organizations to provide explanations in public e-services that increase self-efficacy for citizens. This design principle is particularly applicable to public e-services, as public organizations are obliged to ensure service delivery (Lindgren 2013). Public services, unlike private services, cannot be restricted due to an excess in demand or a lack of human or financial resources (Lindgren 2013). Given the increasing skills shortage in the public sector (Chinn et al. 2020), public organizations rely on the use of public e-services to meet their service needs. To this end, citizens need to be equipped with adequate knowledge with lasting impact to clarify their matters without third-party support. Explanations targeting the functioning of the e-service can equip users with the knowledge to understand the underlying mechanisms of the public e-service (Adadi and Berrada 2018). These underlying mechanisms can provide users with theoretical know-how on how the e-service works and how to act based on the outcomes of the e-service. Thus, we establish that explanations must empower users to act post-interaction with the e-service.

5 Demonstration and evaluation

Following the DSR process, we demonstrated and evaluated the design principles in two subsequent design cycles. For demonstration and evaluation, we instantiated the design principles for the case of the Personal Inflation Calculator of the German Federal Statistical Office. In this section, we present the case and the instantiated design principles, followed by the description of the two design cycles and the evaluation.

5.1 Personal inflation calculator of the German federal statistical office

For evaluation purposes, we selected the case of the Personal Inflation Calculator of the German Federal Statistical Office, which is a typical public e-service of stage 2 (Jansen and Ølnes 2016). The German Federal Statistical Office is a national federal authority with the goal of providing and disseminating statistical

information. It is well suited to study explainability of public e-services for several reasons. First, e-services allow for low-threshold and timely interactions (Williams et al. 2008) and thus constitute an important means for the organization to fulfill its legal obligation to inform the public about statistical topics. Second, the statistical topics to be presented are complex and it is necessary to address each citizen according to their level of knowledge and explain the relations in an understandable way. Third, in its role as an informant of the public, the German Federal Statistical Office plays an important role in the trustworthiness of the public sector (Engel et al. 2019; Sullivan 2020), which is especially important in times of declining trustworthiness in public organizations (dbb 2022; Perry 2021).

One of the German Federal Statistical Office's most frequently used e-services is the Personal Inflation Calculator which allows comparing one's personal inflation rate with the official inflation rate. Indeed, the inflation rate has always been one of the few macroeconomic variables that citizens consider important and relevant to their daily lives (D'Acunto et al. 2019). This was particularly true in 2022 when inflation was the biggest concern in many European countries and especially in Germany (Gebrekal 2022). While it is a rather simple formula to calculate, citizens find it difficult to understand the concept (Ranyard et al. 2008) and often fail to correctly estimate and understand the official and their personal inflation rates (Coibion et al. 2022; D'Acunto et al. 2019). Thus, for most citizens, the inflation rate remains a black box especially since it is not clear how spending in single good subcategories such as electricity or fuel affect the (personal) inflation rate. Against this background, the Personal Inflation Calculator can help to better understand the inflation rate. It enables citizens to calculate their personal inflation rate based on their individual monthly consumption spending in 18 good subcategories (e.g., 'Food') from five categories (e.g., 'Food, Beverages & Restaurants') and compare it with the official inflation rate (cf. Fig. 3). The Personal Inflation Calculator exhibits typical characteristics of stage 2 e-services: The purpose of interacting with the Personal Inflation Calculator is to help citizens compare their personal inflation rate with the official inflation rate, thus going beyond the provision of general information. Its content and structure are dynamic and adapt to the needs of users who provide their individual monthly spending. The impact on users involves an update of information and potential behavior change but does not imply legal consequences (Jansen and Ølnes 2016). However, the Personal Inflation Calculator faced some challenges. For example, the German Federal Statistical Office received negative feedback and criticism, mostly related to allegedly incorrect personal inflation rates based on misunderstandings of the concept. Some citizens even implied that the personal inflation rate was intentionally misreported, a fact that demonstrates the limited comprehensibility and lack of trust in the e-service. This also might affect civil servant satisfaction, as far as they must deal with inaccurate or even personal criticism. To address these issues, our design principles were instantiated to further increase the explainability of the Personal Inflation Calculator.

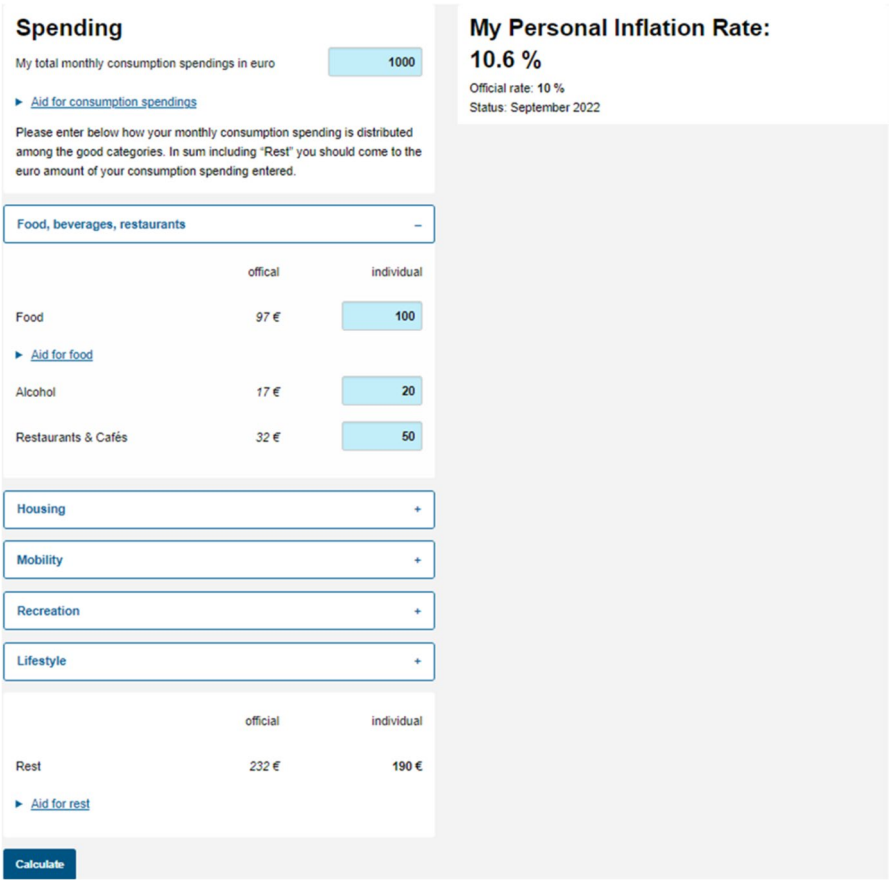

Fig. 3 Illustration of the Personal Inflation Calculator (translated from German)

5.2 Instantiation of the design principles

To address the limitations of the existing Personal Inflation Calculator and to demonstrate the applicability of the proposed design requirements and design principles, we expanded the Personal Inflation Calculator into an explainable e-service, i.e., the Explainable Personal Inflation Calculator. In the following, we describe the Explainable Personal Inflation Calculator [1] and how we instantiated the design principles for the respective context of the application (cf. Table 1).

The new explanation component of the Explainable Personal Inflation Calculator consists of two parts: a basic explanation and a carousel menu (cf. Fig. 4). The basic explanation informs the citizens whether and to what extent their personal

[1] https://service.destatis.de/inflationsrechner/ (explainable version only available in German)

Table 1 Instantiation of the design principles in the explainable personal inflation calculator

Design principle	Implementation in the explainable personal inflation calculator
DP1: Provide explanations that are understandable without prior knowledge	• Use of natural language and easy-to-understand sentences • Start with a basic explanation that does not require prior knowledge • Use of easy-to-understand feature importance in the basic explanation • No unnecessary technical details in all explanations
DP2: Provide a sequential structure of explanations with increasing cognitive informational load	• Simple basic explanation at the top of the website • Opening of a carousel menu, which is initially closed, reveals extended and more complex explanation with increasing cognitive load • Extended explanation builds on basic explanation; interactive element builds on extended explanation
DP3: Provide explanations that are targeted toward citizens' individual situations	• All explanations are based on individual input of the citizens • No (abstract) general explanations of the inflation rate • Use of two local explanation methods (feature importance and counterfactuals) related to citizens' individual situations
DP4: Provide explanations that encourage instant citizen interaction with the public e-service	• Interactive element in the carousel menu • Interactive element is based on the extended explanation to lower the barriers to using the element • Interactive element makes the explanations more tangible • Interactive element gives direct feedback (personal inflation rate with different spending)
DP5: Provide explanations that empower citizens to act post-interaction with the public e-service	• Basic and extended explanations give the citizens a basic understanding of the (personal) inflation rate • Interactive element deepens the understanding, empowering the citizens to decide if and how to optimize their personal inflation rate

inflation rate is higher or lower than the official inflation rate and which three good subcategories most strongly contribute to the deviation. The carousel menu is initially closed and can be opened with a click. There are two subparts within the carousel menu: (a) an extended explanation, where the three main good subcategories are explained in more detail and why they cause a higher or lower inflation rate compared to the official inflation rate, (b) an interactive element, where citizens can adjust their spendings in the three main good subcategories and observe the corresponding effect on the personal inflation rate. During the development of the Explainable Personal Inflation Calculator, we made sure to enable understanding without prior knowledge (DP1). Therefore, we used explanations in simple natural language, as they are more accessible to lay users than,

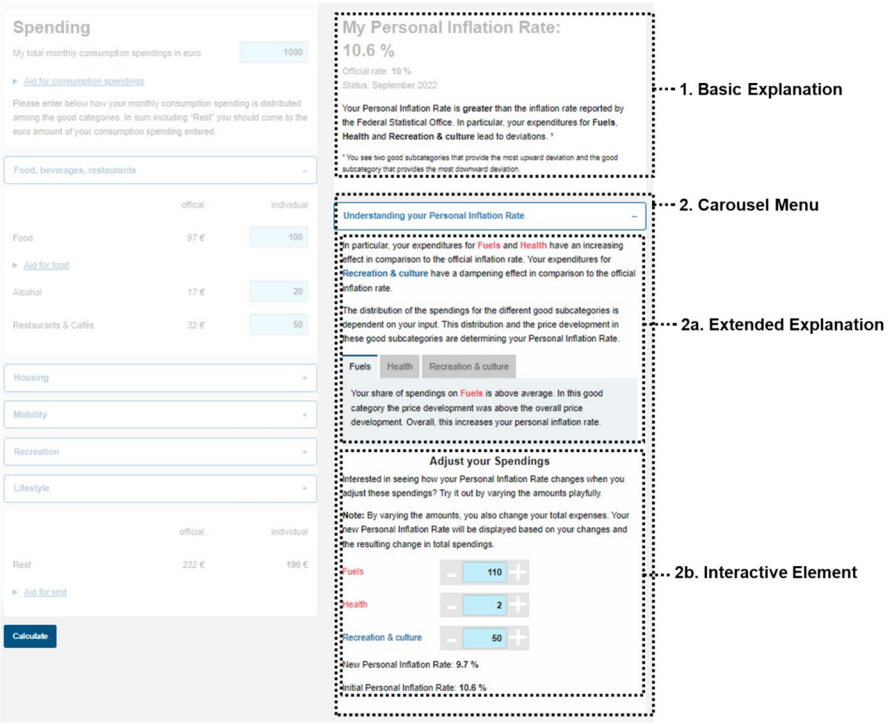

Fig. 4 Illustration of the Explainable Personal Inflation Calculator (translated from German)

e.g., visual explanations (Chromik and Butz 2021). These textual explanations are based on feature importance to instantly guide users' attention toward the most significant contributors to the service's outcome (Ribeiro et al. 2016). Such feature importance explanations are particularly suitable for helping non-experts to quickly gain a general understanding of the topic presented (here, the personal inflation rate) (Bove et al. 2022). In both the basic explanation and the carousel menu, we paid particular attention to using simple and short sentences to make them understandable for citizens without prior knowledge. For example, in the basic explanation, we first state whether the personal inflation rate is higher or lower than the official inflation rate. This gives the most important information first and clearly. In the following sentence, we describe the three subcategories that are most important for the deviation of the personal inflation rate from the official inflation rate. This gives citizens a high-level overview without overwhelming them with information and further details. In the extended explanation, we indicate for each of these three good subcategories whether the spending is above or below average and whether the inflation rate of this subcategory is above or below the official inflation rate, which shows how spending in this good subcategory affects the personal inflation rate (increasing or decreasing). In this way, we gradually increase the complexity of the explanations and give citizens with no prior knowledge the opportunity to understand complex relationships in the area

of inflation rates. Thereby, we also made sure to use a sequential structure with increasing cognitive information load (DP2). To this end, we decided to keep the carousel menu closed at first. This gives the citizen a rather simple explanation of in which direction and why the personal inflation rate deviates from the official inflation rate in a first step. Clicking on the carousel menu reveals more complex explanations, namely the extended explanation and the interactive element. This allows for progressive follow-up, as needed (Springer and Whittaker 2019). Thereby, we made sure that all the explanations are tailored to the citizens' individual situation (DP3). In particular, we refrained from explaining the concept of inflation rate in general (e.g., with formulas). Instead, all explanations are based on the individual citizen's input. For example, the basic explanation lists the three subcategories that are most important for the deviation between the citizen's personal, individual inflation rate and the official inflation rate. In addition, the extended explanation represents counterfactual explanations (Förster et al. 2023) based on the citizens' individual situation. A counterfactual explanation uncovers why a certain outcome (i.e., the citizen's personal inflation rate) results instead of another one (i.e., the official inflation rate) (Wachter et al. 2017). In the literature, counterfactual explanations are considered to be very helpful in explaining individual outcomes because they are similar to human explanations in that they focus on what would have to be changed in an individual situation to achieve a different outcome (Förster et al. 2023). Moreover, they are considered to be particularly accessible to lay users (Cheng et al. 2021). Based on these counterfactual explanations, citizens can use an interactive element to further explore their personal inflation rate and are thus encouraged to instantly interact with the e-service (DP4). To do this, we used input fields and plus/minus buttons to allow changes to be made to the spending for the three subcategories that are most important for the deviation between the personal and the official inflation rate. Citizens can directly see how the changes they have made affect their personal inflation rate, as both the new (based on the changes) and the original personal inflation rate are displayed. By linking the extended explanation and the interactive element, citizens are encouraged to use the interactive element as the theoretical explanations become tangible. In addition, the direct feedback on the interactive changes increases user satisfaction with the tool (Wu 2006). At the same time, citizens are empowered to act post-interaction with the e-service (DP5). One reason for this is that interactivity in online tools in general has been shown to lead to greater learning success (Cho et al. 2009). On the other hand, in this particular case, it is because the playful use of the interactive element allows citizens to gain exciting and sometimes counterintuitive insights (increasing spending can reduce the personal inflation rate in certain cases). This gives them a general understanding of the calculation and concept of the (personal) inflation rate, as well as knowledge of how the e-service works (Mueller et al. 2021). Overall, this enables citizens to evaluate and deduce for themselves whether and to what extent they want to optimize their personal inflation rate. At the same time, they receive initial indications on how to reduce their personal inflation rate and are empowered by the tool to take action in their daily lives.

The design principles presented above resulted from two subsequent design cycles (Peffers et al. 2007). In the following, we describe the instantiation and evaluation of the design principles during these cycles.

5.3 First design cycle

During the first design cycle, we implemented the design principles in form of mockups. To address DP1 (understandable without prior knowledge) and DP3 (targeted toward individual situations), we prepared a textual explanation of the deviation of the personal inflation rate, which contained the crucial determinants for the individual outcome. For DP2 (sequential structure), we provided a drop-down menu that allowed for progressive follow-ups upon demand. We implemented DP4 (interactive elements) by providing interactive elements that visualized users' most crucial determinants for their individual outcomes in form of a radar chart and that allowed users to modify these determinants in form of a controller function. DP5 (empowerment for post-interaction) was addressed by incorporating information on how to adjust the personal inflation rate.

To evaluate the design principles in the first cycle, we conducted a four-hour design workshop with five employees from the German Federal Statistical Office. The participants were recruited from departments responsible for the development and supervision of the Personal Inflation Calculator. The overarching goal was to analyze experts' perceptions and to determine improvement potential. Overall, the employees provided positive feedback which is reflected in illustrative quotes: "The textual explanation is easy to understand"; "The controller function with the most crucial determinants for their individual outcome makes it fun to interact with the system"; "In our experience, it is advantageous that the information is staggered according to the user's information needs". The experts expressed potential for adaptation with regards to DP4 (encouragement of instant interaction), which is evidenced by an illustrative quote: "The graphic in form of a radar chart is too complex and confusing". We used the insights as input for the second design cycle.

5.4 Second design cycle

We refined the design principles during the second design cycle: The former DP1 (understandable without prior knowledge) was sharpened towards no expected knowledge requirements, and the former DP2 (sequential structure) was enhanced by a reference to increasing cognitive informational load. Further, the former DP4 (interactive elements) was revised towards encouragement of instant user interaction. The revised design principles were implemented as a web-based prototype and integrated in the Personal Inflation Calculator. The evaluation during the second design cycle was threefold. First, we conducted a qualitative user study with 226 users to evaluate each design principle from users' perspectives. Second, we evaluated the utility and applicability of the design principles by consulting 17 practitioners (Iivari et al. 2021). Third, to evaluate the impact of the design principles, we conducted a randomized online experiment with 204 users. The results indicated

that no further design cycle was necessary. Thus, the evaluation in the second design cycle represents the final evaluation of our proposed design principles.

5.5 Evaluation

The aim of our evaluation was to evaluate the utility and applicability of our proposed design principles for explainability of public e-services and gain insights into their impact on the use of public e-services. In the following, we describe data collection as well as analysis and results.

5.5.1 Data collection

First, to evaluate the utility of the design principles from users' perspectives, we conducted an online user study. The online study consisted of three phases. First, participants were asked to answer demographic questions. Second, participants were asked to use the web-based prototype (i.e., the Explainable Personal Inflation Calculator). Third, participants were asked to provide qualitative feedback on each design principle based on open-ended feedback fields (see Appendix A1). We recruited 226 participants, comprising 41 employees from the German Federal Statistical Office representing users with domain knowledge, 85 students that were inscribed in data science courses and 100 participants from the platform Clickworker representing lay users. Of the 226 participants, 137 were male and 86 were female (while three did not specify a gender). Most participants were between 20 and 30 years old (46%) or between 30 and 50 years old (40%).

Second, to analyze the utility and applicability of the design principles from practitioners' perspectives, we conducted a survey involving 17 experts in the field of public sector digitalization (Iivari et al. 2021). Experts were chosen since they can assess the practical value of the design principles with respect to different public sector e-services. The survey encompassed three phases. First, demographic questions and a short introduction to the research project. Second, a summary of the design principles. In order to avoid influencing the survey participants too much by the specific instantiation of the design principles in the context of the Explainable Personal Inflation Calculator, we refrained from having the survey participants use the Explainable Personal Inflation Calculator in advance (in contrast to the other analyses conducted as part of our evaluation). However, to avoid potential misunderstandings when presenting the general and perhaps at first glance abstract design principles to the experts, we briefly illustrated them with a screenshot of the Explainable Personal Inflation Calculator, comparable to Fig. 4. Third, questions on the utility and applicability of the design principles. During this actual survey, we explicitly emphasized the focus on the general design principles and did not make any references such as screenshots or text links to the Explainable Personal Inflation Calculator. Overall, we are confident that the design of our expert survey helped us to achieve a good balance between not influencing the survey participants too much by the specific instantiation of the design principles in the context of the Explainable Personal Inflation Calculator and the goal of obtaining meaningful results as

part of this evaluation step. Concretely, in line with Iivari et al. (2021), we measured five constructs: (i) accessibility, which describes successful communication of design principles to re-use; (ii) importance, which refers to design principles as relevant for problem-solving in the real world; (iii) novelty and insightfulness, which indicates whether design principles equip experts with new insights; (iv) actability and guidance, which describes immediate utility of the design principles in practice; and (v) effectiveness, which captures whether design principles are associated with a positive value for practitioners and experts (see Appendix A2). All constructs were measured on a 5-point Likert scale ranging from "(1) strongly disagree" to "(5) strongly agree". The participants exhibited an equal distribution in terms of gender (8 male, 8 female, 1 preferred not to say) and represented a diverse range of working experience in public sector digitalization (1 person with less than 1 year, 4 persons with 1–4 years, 4 persons with 5–9 years, 8 persons with more than 9 years). Additionally, the participants were distributed across various age groups, including 2 persons aged 20–29 years, 6 persons aged 30–39 years, 7 persons aged 40–49 years, and 2 persons aged 50–59 years.

Third, to investigate the impact of explainability on the use of public e-services, we conducted a randomized online experiment with a treatment group and a control group to ensure internal and external validity (Levy and Ellis 2011). For this purpose, we recruited German native speakers from the platform Clickworker to obtain structured and unbiased user feedback from non-experts. The experiment consisted of three phases. First, participants were randomly assigned to the control or treatment group and asked to answer demographic questions. Second, people in the treatment group were asked to use the Explainable Personal Inflation Calculator, while people in the control group were asked to use the former, non-explainable Personal Inflation Calculator. Both groups were asked to enter their monthly consumer spending in the personal inflation calculator and receive their personal inflation rate. In the case of the treatment group, participants additionally engaged with the resulting explanations. Third, all participants were asked to answer a survey, which comprised five constructs: (i) perceived ease of use, (ii) usefulness, (iii) intention to use, (iv) self-efficacy, and (v) trust (Davis 1985, 1989; Meske and Bunde 2023) (see Appendix A3). The constructs reflect the four design requirements as well as intention to use as an overarching goal of explainability. All constructs were measured on a 5-point Likert scale ranging from "(1) strongly disagree" to "(5) strongly agree". In total, we recruited 204 participants who passed all attention checks (e.g., eight yes/no questions on whether certain elements such as an inflation comparison to the previous year appeared on the e-service to check if participants actually used the e-service) with 97 participants in the control group and 107 participants in the treatment group. Of the 204 participants, 103 were male and 98 were female (the remaining three did not specify a gender). Over 50% of the participants were between 30 and 50 years old, 19% of the participants were between 20 and 30 years old (19%), and 15% of the participants were between 50 and 60 years old. Chi-squared tests indicated no significant differences in demographic variables between the treatment and the control group. For more detailed evaluation, we further tracked the behavior of all participants using the public e-service during the experiment (e.g., clicking patterns). We focused on the behavior of the participants regarding the interactive

elements (cf. Fig. 4), where citizens can playfully modify the most crucial determinants for their individual outcomes and instantly observe corresponding effects. For each participant, we assessed whether the interactive element was used.

5.5.2 Analysis and results

First, we analyzed the qualitative feedback of the online user study using thematic analysis (Braun and Clarke 2006) to gain insights on the utility of the design principles from users' perspectives. Overall, all five design principles were evaluated positively by all three user groups. While users showed particularly high satisfaction levels with regards to DP1, DP3, and DP5, contentment was slightly lower for DP2 with feedback indicating fluctuating depth of information preferred as well as for DP4 with feedback indicating a lack of practicality. A detailed summary of responses and quotes can be found in Appendix A4.

Second, to assess the utility and applicability of the design principles from practitioners' perspectives, we analyzed the constructs from the expert survey. Cronbach's alpha was >0.75 for all constructs showing good reliability (Taber 2018). The findings of the survey were positive, reflecting the high quality of the proposed design principles (cf. Table 2). Notably, the constructs of importance and accessibility emerged as particularly noteworthy, garnering the highest mean scores of 4.39 and 4.22, respectively. Furthermore, the construct of effectiveness also received a commendable mean score of 4.09. The constructs of actability and guidance as well as novelty and insightfulness received slightly lower mean scores of 3.93 and 3.71, respectively, but they still demonstrated positive evaluations from the experts.

Third, to analyze the impact of explainability on the use of public e-services, we compared the constructs of the online experiment between the treatment group and the control group. To assess the reliability of the constructs, we calculated Cronbach's alpha, which showed good (>0.8) reliability (Taber 2018) except for self-efficacy in the treatment group which showed acceptable (0.66) reliability (Taber 2018). For statistical comparison, we used one-sided Mann–Whitney U tests (Ruxton 2006) as a non-parametric alternative to t-tests since Shapiro–Wilk tests (Razali and Wah 2011) revealed that we cannot assume normality.

Results reveal that participants in the treatment group rated all five constructs significantly higher than participants in the control group (cf. Table 3). Specifically, there were significantly higher values for perceived ease of use (control group 3.54;

Table 2 Results for the assessment of the design principles from the expert survey

Construct	N	Mean	STDV	Cronbach's Alpha
Accessibility	17	4.22	0.77	0.92
Importance	17	4.39	0.60	0.79
Novelty and Insightfulness	17	3.71	0.85	0.76
Actability and Guidance	17	3.93	0.80	0.81
Effectiveness	17	4.09	0.64	0.77

Table 3 Results of the investigation of the impact of explainability from the online experiment

1. Construct	2. Treatment	3. Mean	4. STDV	5. Cronbach's Alpha	6. Mann–Whitney U
Perceived Ease of Use	Non-explainable	3.54	0.98	0.89	U = 41,923.5 p = 0.0268*
	7. explainable	3.68	0.96	0.89	
Perceived Usefulness	Non-explainable	3.38	1.00	0.90	U = 38,730.5 p = 0.0004***
	8. explainable	3.68	0.95	0.89	
Trust	Non-explainable	3.33	1.00	0.85	U = 115,261.0 p = 0.003**
	9. explainable	3.52	0.91	0.83	
Self-Efficacy	Non-explainable	3.25	1.04	0.80	U = 37,103.5 $p < 10^{-4}$***
	10. explainable	3.61	0.96	0.66	
Intention to Use	Non-explainable	2.48	1.24	0.96	U = 40,790.5 p = 0.0080**
	12. explainable	13. 2.71	14. 1.13	15. 0.97	

*5% significance level, **1% significance level, ***0.1% significance level

treatment group (T): 3.68), perceived usefulness (C: 3.38; T: 3.68), self-efficacy (C: 3.25; T: 3.61), intention to use (C: 2.48; T: 2.71), and trust (C: 3.33; T: 3.52). To gain more detailed insights, we conducted additional analyses regarding the use of the interactive element. We used the clickstream data to divide the treatment group into two subgroups: (a) users who used the interactive element (use), (b) users who did not use the interactive element (no-use). Results of statistical comparison between these subgroups reveal that users who used the interactive element perceived higher usefulness (use: 4.08; no-use: 3.61; U = 4578.0; p = 0.004**) and trust (use: 3.85; no-use: 3.46; U = 13,720.5; p = 0.002**) compared to users who did not use the interactive element.

6 Discussion

With our work, we aimed to expand IS literature on the transformative effects of digitalization in the public sector by examining the potential of explainability for use of public e-services. We developed design principles and implemented them using the example of the Personal Inflation Calculator of the German Federal Statistical Office. We evaluated their utility and applicability from users' and practitioners' perspectives and investigated their impact on the use of public e-services.

Our contribution to IS literature and e-government research is twofold. First, we establish design principles for explainability of public e-services of stage 2 (cf. Goldkuhl and Persson 2006; Jansen and Ølnes 2016), which provides applicable and prescriptive knowledge on explainability of public e-services and can be reused and enhanced in future research (Gregor et al. 2020; vom Brocke et al. 2020). Our design principles constitute design knowledge in the form of operational design principles and can be transferred to real-life applications (Gregor et al. 2020; vom Brocke et al. 2020). We contribute to IS research by providing prescriptive knowledge on the explainability of public e-services. While DP1, DP2, and DP5 are specific to public e-services, DP3 and DP4 are transferred from related design principles in the private

sector. All design principles were positively acknowledged by users and experts in the field of public sector digitalization. Additionally, we have demonstrated the practical applicability of the design principles by a successful implementation in a prominent public e-service in cooperation with the German Federal Statistical Office. Specifically, we used the design principles to transform the Personal Inflation Calculator into the Explainable Personal Inflation Calculator. Beyond this specific instantiation, we expect that our design principles to be particularly applicable to public e-services in stage 2 (interaction), which allow users to interact with government agency databases by offering enhanced search, filtering, and calculation services, such as managing debt or accessing government subsidies (Goldkuhl and Persson 2006). Our case exhibits typical characteristics of stage 2 (interaction) public e-services. Examples of similar public e-services include the Pension Calculator provided by the German Pension Insurance and the Parental Allowance Calculator from the Federal Ministry for Family Affairs, Senior Citizens, Women, and Youth. Practitioners confirm the reusability of our design principles. Our expert survey highlighted the applicability and practical impact of the design principles. Experts highlighted their potential for application in public e-services beyond stage 2 services, indicating their capacity for broader adoption and implementation beyond the scope of our initial study.

Second, our study contributes to IS literature on explainability by showing that explainability can improve the use of public e-services. Despite the necessity of a digital transformation of the public sector being widely acknowledged, its implementation remains rather challenging (Alvarenga et al. 2020). Little use is made of public e-services (Heuberger and Schwab 2021) mainly due to a lack of intelligibility, hindering citizens from scrutinizing the services' outcome. Our results demonstrate that explainability can increase intention to use public e-services, as citizens being confronted with an explainable public e-service show significantly higher use intentions than those interacting with a non-explainable service ($p < 0.01$). In line with this finding, explainability further improves the underlying key levers of usage (Davis 1989), namely usefulness and ease of use: Citizens evaluate an explainable public e-service as significantly more useful ($p < 0.01$) and easy to use ($p < 0.05$) than a non-explainable service. Our insights expand existing IS literature that suggests a positive effect of explainability on adoption (Conati et al. 2021) in other domains like healthcare, finance, robotics, and law (Minh et al. 2022). We are the first to demonstrate the positive effect on citizens in the public sector. Furthermore, our study demonstrates the value of explainability in establishing trust in public e-services. Citizens being confronted with an explainable public e-service trust it significantly more ($p < 0.01$) compared to a non-explainable service. This insight is of relevance as the German state faces a sharp decline in trustworthiness among citizens with only 29% of citizens considering the state to be capable of fulfilling its duties (dbb 2022). Such loss in trustworthiness has implications for public organizations as nearly 50% of the population has reported a perceived performance decline in the public sector (dbb 2022). This worrying trend has the potential to further hinder digitalization as citizens will only use public e-services if they trust them (Carter and Bélanger 2005). As trust in public e-services is closely connected to trustworthiness in respective public organizations, the results of our study demonstrate a

possible pathway to contribute to counterbalancing the loss of trustworthiness in the public sector by providing explainable public e-services.

Next to these theoretical contributions, our findings indicate two practical implications. First, our design principles can be implemented to develop explainable public e-services or to introduce explainability into existing ones. The positive evaluations received from users and experts attest to the design principles' potential to transform the landscape of public e-services. Furthermore, the practical applicability of our design principles was demonstrated through their successful instantiation in the Personal Inflation Calculator of the German Federal Statistical Office. This instantiation showcased how our design principles can be effectively utilized to enhance the interpretability of public e-services. Second, our insights on the impact of explainability on the use of public e-services serve public sector organizations to anticipate the impact of explainability when they implement explainable public e-services. Our study suggests that explainability improves use intentions of public e-services while increasing ease of use and usefulness. Furthermore, by increasing citizens' self-efficacy, explainable public e-services can help citizens be less reliant on civil servants for guidance. Accordingly, public organizations should cluster existing e-services based on the current degree of assistance required by citizens. E-services causing high administrative effort through civil servants' guidance could be first enriched by explainability, while gradually expanding those onto other public e-services. Moreover, explainable public e-services can be a lever to support public organizations in shaping their external societal perception as accountable points of contact. Our results indicate that citizens being confronted with explainable public e-services trust the corresponding e-services more than those operating with non-explainable e-services. Hence, explainability can help to counterbalance the overall declining trustworthiness in public organizations. Thus, public organizations should consider leveraging explainability for e-service transformation and showcasing their explainability to citizens.

7 Conclusion

Despite an omnipresent call for public e-services, the potential of digitalization in the public sector remains untapped. This lack of progress is mainly due to missing adoption of public e-services. Literature on explainability of IS offers inspiration and promising approaches and has already demonstrated its ability to improve use of e-services in various private sector domains. However, there is an insufficient understanding of how explainability may improve use of public e-services. In this paper, we developed and evaluated design principles for explainability of public e-services and empirically investigated whether explainability can improve use of public e-services. In a lighthouse project with the German Federal Statistical Office, we instantiated our design principles to extend their Personal Inflation Calculator to an explainable e-service. To evaluate the utility and applicability of the design principles, we conducted a qualitative user study and an expert survey. Results were positive, which demonstrates utility and applicability of the design principles. To investigate the impact of explainability on the use of

public e-services, we conducted a randomized online experiment with 204 participants. Our results reveal that explainability can improve use of public e-services by increasing citizens' perceived ease of use, usefulness, intention to use, self-efficacy, and trust. We are the first to identify explainability as an amplifier for the use of public e-services amongst citizens. Further, we provide first insights into explainability's potential to improve use of public e-services.

While our research presents first interesting insights, several limitations remain and may serve as a starting point for future research: First, our research focuses on one specific case, the Personal Inflation Calculator as one of the most prominent and frequently used e-services of the German Federal Statistical Office and has been evaluated with German citizens. This approach could be complemented by future investigations of even more complex public e-services, e.g., AI-based e-services. Second, our insights on explainability's positive impact on citizens' use of public e-services should be complemented by investigations on civil servants' acceptance. Third, while our findings demonstrate positive effects of explainability, explainability is not the only lever for successful digitalization. Future research should investigate the possibilities of faster deployment and central coordination in combination with explainability. Fourth, our evaluation of design principles through an expert survey is based on a relatively small sample size. While it complements our findings from the qualitative user study and randomized online experiment with first interesting insights from public sector digitalization experts, a larger sample size would promise richer insights regarding utility from practitioners' perspectives and thus constitutes an important avenue for future research. Moreover, we acknowledge that the brief illustration of the design principles using a screenshot of the Explainable Personal Inflation Calculator as part of the introduction to the survey might have influenced the experts in their evaluation of the general design principles. Finally, despite a well-founded derivation, design requirements and design principles can never be complete. Future research should further investigate our design requirements and design principles and extend them if necessary.

Appendix

A.1 Questions of the qualitative online study

Design principle	Question
DP1	How do you assess the personal inflation calculator in terms of comprehensibility, particularly with regard to your prior knowledge?
DP2	How do you assess the sequential structure of the personal inflation calculator?
DP3	How do you assess the individual explanations of the Personal Inflation Calculator?
DP4	How would you assess the interaction component of the Personal Inflation Calculator?
DP5	How do you assess the personal inflation calculator in terms of actionability?

A.2 Constructs and items of the expert survey

Construct	Item
Accessibility	The design principles are easy for me to understand
	The design principles are easy for me to comprehend
	The design principles are intelligible to me
Importance	In my view the design principles address a real problem in developing explainable public e-services in public sector communication
	In my view the design principles address an important—acute or foreseeable—problem in developing explainable public e-services
	In my view the design principles represent an important source of information for the development of explainable public e-services
Novelty and insightfulness	I find that the design principles convey new ideas to me
	I find the design principles insightful to my own practice
	I find that the design principles communicate novel design opportunities or design combinations
Actability and guidance	I think that the design principles can realistically be carried out in practice
	I think that the design principles can easily be carried out in practice
	I find that the design principles provide sufficient guidance for developing explainable public e-services
	I find that the design principles provide sufficient direction for explainable public e-services
	I find that the design principles are not restrictive when designing such explainable public e-services
	I find that the design principles provide me with sufficient freedom when designing such explainable public e-services
Effectiveness	I believe that the design principles can help develop explainable public e-services
	I find the design principles useful for developing explainable public e-services
	Compared to my current situation, I believe that the design principles would improve my performance in developing explainable public e-services
	Compared to my current situation, I believe that the design principles would increase my productivity in developing explainable public e-services
	Compared to my current situation, I believe that the design principles would enhance my effectiveness in developing explainable public e-services

A.3 Constructs and items of the online experiment

Construct	Item
Perceived ease of use	The user interface of the Personal Inflation Calculator is user-friendly
	I find it easy to navigate the user interface of the Personal Inflation Calculator
	I find the user interface of the personal inflation calculator clear and easy to understand

Construct	Item
Perceived usefulness	The Personal Inflation Calculator user interface is useful for understanding how my personal inflation rate is affected by the distribution of my consumer spending
	The user interface of the Personal Inflation Calculator helps me to find out how the distribution of my consumer spending affects my personal inflation rate
	The user interface of the Personal Inflation Calculator increases my understanding of how the distribution of my consumer spending affects my personal inflation rate
Self-efficacy	I am confident that I understand the deviation of my personal inflation rate from the official inflation rate
	I think I have understood the extent to which my personal inflation rate is influenced by my monthly consumer spending in individual goods subcategories
	I feel able to influence my personal inflation rate in a targeted manner by changing my monthly consumer spending in individual areas of goods
Use intention	If possible, I intend to use the Personal Inflation Calculator over the next six months
	If possible, I expect to use the Personal Inflation Calculator over the next six months
	If possible, I plan to use the Personal Inflation Calculator over the next six months
Trustworthiness	You can use the personal inflation calculator to obtain reliable information about your personal inflation rate
	I trust that the Personal Inflation Calculator is working properly
	I trust that the Personal Inflation Calculator will take my interests into account
	All in all, the Personal Inflation Calculator provides a reliable source of information
	I believe that I can trust the Personal Inflation Calculator

A.4 Results of the qualitative online survey

Design principle	Summary of responses	Example quotes
DP1	Participants found the textual explanations clear and easy to understand, with several praising the use of simple language suitable for non-experts. Most agreed that the explanations should be concise, noting that the current length was appropriate, though a few felt they were too brief	"For me, the explanations are understandable and completely sufficient" "Easy to understand, although I have not used any inflation calculator before" "Sufficient for the purpose, but I don't know if this is enough for people without a business background" "They are sufficient and not too long. Additional information could be provided via a link" "It could be explained in more detail, if necessary, but it's enough for a first glance"

Design principle	Summary of responses	Example quotes
DP2	Most participants agreed that the sequential structure of the explanations enhanced understanding and clarity of the public e-service preventing information overload. However, few did not grasp the click-to-reveal additional explanations	"The structure was very clear" "Sometimes I had the feeling that the information was hidden" "Too little explanation; you only get it if you actually search for it" "I think the structure is good because it makes it easier to understand, especially because you're not overwhelmed by the information" „I like the carousel element, it gave the explanations a clear structure"
DP3	Participants were remarkably consistent in their positive assessment of the personalized explanations target towards users' individual situations. The explanations were perceived highly beneficial, enabling a clear understanding of their personal inflation rate and deviations from the official rate. However, a minority expressed criticism, primarily due to inadequate explanation quantity	"Helpful for comprehending what drives my personal inflation rate" "Good for people familiar with the subject, perhaps a little too in-depth for the general public" "Yes, whether you are more affected by inflation because the products you have more/less of than the average are more or less affected by inflation" "I have understood" "I need far more explanations"
DP4	The options for instant user interaction with the e-service received commendation from most participants. Many noted its effectiveness in illustrating how individual spending subcategories influence the inflation rate. Some highlighted its value as a complement to textual explanations, allowing users to explore various spending combinations. Few participants encountered difficulties in distinguishing between their initially calculated inflation rate and the revised rate when adjusting spendings	"I like it! It helps me to plan adaptions" "This is a good opportunity to try out how changes work" "Very good, but somewhat illusory, as gas/fuel oil prices are predetermined, are part of the comfort of life, and therefore cannot really be significantly reduced."
DP5	Participants mostly agreed that the public e-services empowered them to take action post-interaction. In particular, the ability to test different numbers was beneficial. Some appreciated how it prompted them to consider potential cost-cutting measures. However, others criticized its lack of practicality, noting constraints in reducing costs in certain areas. Nonetheless, the tool was valued for enhancing understanding of the inflation rate	"I like it, I wouldn't change it" „I have the feeling that I now understand better how the inflation rate is calculated" "Helped me to understand how the inflation rate is calculated" "Sometimes seems unrealistic"

Funding Open Access funding enabled and organized by Projekt DEAL.

Data availability The dataset generated during the current study is not publicly available as it contains proprietary information that the authors acquired through a license. Information on how to obtain it and reproduce the analysis is available from the corresponding author on request.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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