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DeCACHe: Supporting Designers in Creating Cognition-Centered Adaptive Cultural Heritage Activities

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Received: 20 July 2019; Accepted: 27 August 2019; Published: 31 August 2019

Abstract: Cultural heritage (CH) institutions attract wide and heterogeneous audiences, which should be efficiently supported and have access to meaningful CH content. This introduces numerous challenges when delivering such experiences, given that people have different cognitive characteristics which influence the way we process information, experience, behave, and acquire knowledge. Our recent studies provide evidence that human cognition should be considered as a personalization factor within CH contexts, and thus we developed a framework that delivers cognition-centered personalized CH activities. The efficiency and the efficacy of the framework have been successfully assessed through two user studies, but non-technical professionals (e.g., CH designers) may face difficulties when attempting to use it and create personalized CH activities. In this paper, we present *DeCACHe*, which supports CH designers in creating cognition-centered personalized CH activities throughout different phases of the design lifecycle. We also report a user study with seventeen professional CH designers, who used our tool to design CH activities for people with different cognitive characteristics.

Keywords: cultural heritage; cognition; cognitive characteristics; personalization; adaptation; design support; activity design; user modeling

1. Introduction

Several cognitive theories [1,2] suggest that people differ in the way we think, sense, and experience, and thus we develop unique functions and processes to acquire, perceive, handle, and recall information. Such differences often result from our cognitive characteristics, such as cognitive styles and abilities, which build a unique cognitive profile for each individual [2]. For example, people who are characterized as visualizers (i.e., individuals who process and mentally represent information visually) tend to acquire information and build mental connections to process it through pictorial content, such as images; on the other hand, people who are characterized as verbalizers (i.e., individuals who process and mentally represent information verbally) tend to rely on textual content, such as text passages, to perform the aforementioned processes [3].

In the cultural heritage (CH) domain, recent research provides evidence that such cognitive characteristics influence the way individuals visually explore CH scenes [4], develop their visiting style [5], interact with CH exhibits [6], and gain information through interaction [7] in varying CH activities [8] and technological contexts [9]. Therefore, individuals with different cognitive profiles tend to develop different strategies to process CH information, which may result in imbalances on their performance [6], experience [9], content comprehension [10], and knowledge acquisition [11].

The findings of the aforementioned studies suggest the personalization of CH activities based on the cognitive profile of the end-users (e.g., museum visitors). Our recent works [12,13] provide evidence that we can build adaptive interventions which leverage visitors' cognitive profile to enhance their experience and improve their knowledge acquisition. Our cognition-centered personalization framework [13] aims to deliver CH activities tailored to the users' cognitive profile. The results of two user-studies verified the applicability, effectiveness, and efficiency of the framework and underpinned the added value of adopting cognition-centered personalization interventions within digitized CH interaction contexts.

However, non-technical stakeholders (i.e., people who do not have the expertise to take part in software development processes; however, they might be experienced in related fields, such as system or interaction design), such as CH designers, might face difficulties in understanding, learning, and applying the technical details of the cognition-centered framework. Hence, there is a need for supporting them to create cognition-centered personalized CH activities through a standalone tool. Motivated by that need, in this paper, we (i) present *DeCACHe* — which is the acronym for "***De***sign of ***C***ognition-centered ***A***daptive ***C***ultural ***He***ritage activities" — that is a tool that helps CH designers to make design decisions to support users with different cognitive characteristics when creating cognition-centered personalized CH activities; and (ii) we report an evaluation study, in which seventeen professional CH designers used *DeCACHe* to create a personalized CH activity.

The remainder of the paper is structured as follows: firstly, we discuss the related work and present the motivation of this research endeavor; next, we present the design of *DeCACHe*, covering the aspects of the theoretical background and the architectural model; finally, we present the user study, discuss its impact, its limitations, our future steps and conclude the paper.

2. Related Work and Motivation

2.1. Related Work

In this section, we discuss the cognition as a personalization factor, our recent cognition-centered framework [13] for delivering personalized CH content, tools that have been developed to create CH activities, and tools that focus on creating personalized CH activities.

Cognition as a personalization factor. Cognition is one of the basic user-modeling factors that could lead to meaningful personalization mechanisms when the activities entail information processing tasks [14], which are common in the CH domain. The main objectives of cognition-related works in the CH domain are to reduce the cognitive load and amplify the cognition through various information–visualization techniques, such as adoption of multi-method interfaces [15], reduction of information search and use of perceptual attention mechanisms for monitoring [16], and cognitive content-based adaptation for emotional experiences [17]. While these works focus on amplifying the cognition regardless of the users' individual cognitive characteristics, recent studies revealed that individual cognitive characteristics influence users' performance [6], experience [9], visual and interactive behavior [7,8,11], visiting style [5], and knowledge acquisition [18] within CH contexts.

These findings are in line with several socio-cognitive theories [1,2], which suggest that individuals differ in the way we process information, depending on our cognitive profile which is built on unique characteristics, such as cognitive abilities/skills (i.e., the ability to learn, to process and apply knowledge, to analyze, to reason, to evaluate and to decide) and cognitive styles (i.e., the typical mode of thinking, remembering or problem-solving, which refer to the preferred way of processing information). Such theories suggest that the information-processing approach of individuals with specific cognitive characteristics affects their behavior while performing an activity to accomplish an objective. The theoretical and practical evidence of the importance of considering cognition as a personalization factor motivated us to develop a cognition-centered personalization framework for CH content, which we discuss next.

Cognition-centered personalization framework for CH content. In our recent work [13], we presented a framework that helps CH stakeholders (e.g., CH designers, CH institutions, CH educators) in providing personalized CH activities to the visitors through adaptive interventions that leverage the visitors' cognitive profiles. The framework consists of three stages: (a) the design of personalized CH activities; (b) the visitor modeling based on selected cognitive factors; and (c) the configuration and delivery of the personalized CH activity to the visitor. The first stage is performed before the visit while the other two stages are performed during the visit. Hence, through our framework, a CH designer receives personalized recommendations that would help them to create different versions of a CH activity that build on the unique cognitive profile of the potential visitors, and, then, the personalized CH activity is delivered to each visitor through rule-based techniques, which map each visitor's cognitive profile with the corresponding rules of content adaptation. The cognitive profiles are built dynamically through real-time modeling based on users' behavioral data (e.g., eye-tracking data, interaction data). The results of three user-studies [12,13] revealed that the visitors who used the cognition-adapted CH activities had an enhanced experience and an improved knowledge acquisition in comparison to the visitors who used the original CH activities. However, we should stress that the configuration of the framework required the modification of technical details that our research team was aware of, but they can be a burden for non-technical CH stakeholders, such as designers. Hence, there is a need for providing a standalone authoring-like tool for supporting CH designers in easily creating cognition-centered personalized CH activities.

Tools for creating CH activities. Considering that the existence of tools that support CH designers in creating CH activities without the intervention of technical partners improves the sustainability and the expandability of CH systems, several tools have been proposed to support designers in creating interactive CH activities. Such tools can be used by CH designers to create and manage CH content [19], create CH games [20,21] create annotations by linking spatiotemporal data [22,23], create interactive storytelling experiences [24,25], create multimedia applications [26], create navigational structures for virtual exhibitions [27], create chat-bots [28], etc. Moreover, the authoring tools can have different characteristics, such as leveraging open and structured data to create CH activities [29], combining multiple types of resources [30], and supporting co-designing [31,32] with varying types of CH stakeholders (e.g., curators, educators, content providers, visitors). Finally, the authoring tools can be used to produce CH activities in varying technological contexts such as mobile devices [33], location-aware contexts [34], augmented reality [35], and virtual reality [36]. The aforementioned research attempts support CH designers in creating CH activities, but they do not support personalization, which is a desideratum in the CH domain [37].

Tools for creating personalized CH activities. Focusing on research attempts that aim to create tools that support the design of personalized CH activities, Androutsopoulos et al. [38] presented an authoring tool that generates multilingual personalized descriptions of museum exhibits; Konstantopoulos et al. [39] presented an authoring environment for creating abstract semantic representations of CH object descriptions tailored to the profile of the audience; Not and Petrelli [40] recently presented the *meSch* authoring tool that supports CH designers in creating personalized and interactive CH experiences for visitors in diverse CH settings; Ardito et al. [41] presented a visual composition paradigm that allows non-technical CH professionals to manage ecosystems of interoperable smart objects and synchronize their behavior to create enhanced visit experiences; Katifori et al. [42] presented a tool that enables CH content providers and experts to create personalized and dynamically adaptive digital narratives, based on visitors' profile (e.g., interests, visiting behavior), in archaeological sites. While the aforementioned research attempts support CH designers in creating personalized CH activities, they do not take into consideration the cognition factor, which is an important personalization factor for CH [13] and other domains [14]. Research attempts in other domains, such as education [43,44] that enable creators to incorporate cognition factors in their applications, motivate us to build a tool for supporting CH designers in creating cognition-centered personalized CH activities.

2.2. Motivation

From the discussion on the related work, it is evident that tools that support the design of digitized CH activities enable CH professionals, who have limited or no technical expertise, to create meaningful CH activities, and thus they benefit the end-users, as they receive enhanced visit experiences. Considering that the cognition-centered framework [13] aims to provide enriched CH experiences tailored to the visitors' cognitive profiles, there is a need for designing a tool that could be used by CH designers to create the appropriately adjusted CH activities. Therefore, motivated by the aforementioned rationale, in this paper, we (i) present the design of *DeCACHe*, which is a tool that supports the design of cognition-centered personalized CH activities; and (ii) evaluate *DeCACHe* through a user study in which seventeen professional CH designers used our tool to adjust their CH activities and create experiences tailored to the visitors' cognitive profiles.

3. Design of *DeCACHe*

3.1. Theoretical Background

Design support. Following design research methodology [45], *DeCACHe* supports design decisions through the various stages (*DS*) of the design cycle, such as task clarification, conceptual design, embodiment design, and detailed design. The aforementioned stages reflect specific design functions (*DF*), such as task definition, choice of representations, choice of methods, and definition of visualization, interaction, and distribution strategies. In turn, according to Fu et al. [46], the aforementioned functions are supported by providing well-defined design concepts (*DC*), such as design principles (i.e., fundamental rules or laws, derived inductively from extensive experience and/or empirical evidence, which provide design process guidance to increase the chance of reaching a successful solution), design guidelines (i.e., context-dependent directives, based on extensive experience and/or empirical evidence, which provide design process direction to increase the chance of reaching a successful solution), and design heuristics (i.e., context-dependent directives, based on intuition, tacit knowledge, or experiential understanding, which provide design process direction to increase the chance of reaching a satisfactory but not necessarily optimal solution). By adopting the derived concepts in their design cycle, the CH designers can create personalized CH activities that build on and take advantage of the visitors' cognitive profiles.

Design factors. As discussed in Raptis et al. [13], the cognition-centered personalization framework is based on three main factors: activity (*AF*), objective (*OF*), and cognition (*CF*), which are interrelated with each other. *AF* contains information about the activity characteristics, such as type (e.g., exploratory visual search, goal-oriented visual search), areas of interest (e.g., areas that contain critical CH information), and mechanics (e.g., interaction mechanisms that provide CH information); *OF* contains information about the objective (e.g., improve knowledge acquisition, enhance visit experience) of the CH activity; *CF* contains information about the visitors' cognitive profile (e.g., cognitive style, cognitive abilities) that can be used as the basis for the creation of adaptive cognition-centered interventions. For example, in a recent study [10], we investigated whether and how the visual working memory influences the knowledge acquisition of the visitors when they perform a virtual tour; in this case, *AF* is the *virtual tour*, with characteristics such as exploratory visual search (the visitors were free to view any paintings they were interested in, with no time restrictions) and point-and-click interactions (the visitors needed to focus on a painting and click on it in order to receive information about it), *OF* is the *knowledge acquisition* of the visitors (the objective of the creator of the tour was to help the visitors learn about the collection); *CF* is the *visual working memory* capacity. The results of the study showed that people who were less efficient in storing and managing visual information (i.e., people with low visual working memory capacity) produced shorter fixations, meaning that they were less focused and attentive during the CH activity.

Hence, they could not comprehend the visual information and perceive the context of the painting as deeply as individuals with high visual working memory capacity. This was reflected in the content comprehension, as the lower visual working memory capacity an individual had, the lower scores they achieved in the post-session content comprehension and knowledge acquisition tests. The derived design concepts depend on this triple, meaning that we need to take into consideration these factors (AF, OF, CF) to provide the most appropriate design concepts (e.g., principles, guidelines, heuristics).

3.2. Architecture

From the discussion on the theoretical background of the tool, it is evident that *DeCACHe* aims to deliver a collection of design concepts (Equation (1) to the CH designers and support them in designing cognition-centered personalized CH activities:

$$Set_{design\ concepts} = \{DC_1, DC_2, ..., DC_N\}\,. \tag{1}$$

Each design concept (DC) can be a principle (DCp), a guideline (DCg), or a heuristic (DCh), and it is characterized by the design stage (DS), the design function (DF), the activity characteristics (AF), the objective of the activity (OF), and the supported cognition factor (CF). These factors are interrelated with each other and when combined, *DeCACHe* delivers a design concept (Equation (2)):

$$f : \langle DS, DF, AF, OF, CF\rangle \rightarrow DC \in Set_{design\ concepts}. \tag{2}$$

In particular, the delivered design concepts are the ones that are mutually parts of the DS, DF, AF, OF, and CF sets. Therefore, *DeCACHe* recommends a set of design concepts that meet the requirements of the intersection of the aforementioned sets (Equation (3)):

$$Set_{design\ concepts} = Set_{DS} \cap Set_{DF} \cap Set_{AF} \cap Set_{OF} \cap Set_{CF}. \tag{3}$$

The architectural model (Figure 1) of *DeCACHe* consists of three main tiers:

1. *Front-End*: End-users operate on this tier and they are not aware of the existence of the back-end and the design-space database beyond this layer. All views provided in this tier are generated by applications that reside in the back-end tier. Through the *Setup* component, the CH designers initialize the design process and provide the selection criteria (design stage/function, activity, objective). Through the *Results* component, the CH designers receive the recommended design concepts and cognition factors.
2. *Back-End*: At this tier reside the application server and the methods that access the design-space database (e.g., create requests to the database based on the selection criteria, receive matched design concepts). This tier presents an abstracted view of the database; it resides in the middle and acts as a mediator between the end-user and the design-space database.
3. *Design-Space Database*: At this tier, the collections of interrelated data-sets reside along with the database query processing languages. This tier also provides the relations that define the data and their constraints at this level.

To better understand the process for supporting CH designers in creating cognition-centered adaptive CH activities, we present its main steps (Figure 1):

1. The CH designer initializes the tool by selecting the activity characteristics (e.g., visual search activity), the objective of the activity (e.g., enhance immersion), and the design stage or function in which they will apply the derived concepts (e.g., definition of interaction strategies);

2. The selected features form a vector (3-tuple) which is sent to the back-end tier;
3. Through the application logic, *DeCACHe* requests and receives the design concepts, which meet the selection criteria, from the design-space database;
4. The back-end tier returns the matched design concepts along with the corresponding cognitive factors to the front-end tier;
5. The CH designer receives the matched design concepts (along with the cognition factors) and uses them to create new CH activities or adjust existing ones, tailored to the visitors' cognitive profiles.

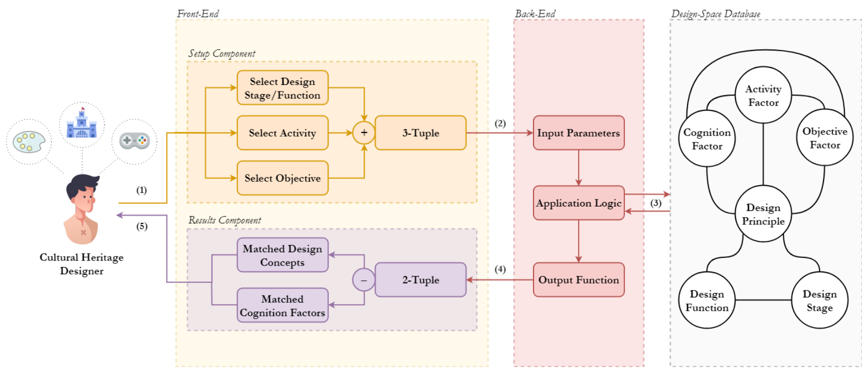

Figure 1. The architecture of the *DeCACHe* tool: (1) the cultural-heritage (CH) designer selects the activity, the objective, and the design stages/functions to apply the design concepts; (2) the selected features are sent to the back-end tier; (3) through the application logic, *DeCACHe* requests and receives the design concepts, which meet the selection criteria, from the design-space database; (4) the matched design concepts and cognition factors are returned to the front-end tier; (5) the matched features are presented to the CH designer.

Focusing on the design-space database, which is a core component of *DeCACHe*, we should stress its dynamic nature. The stored design principles, which are in textual format, can be modified by authorized users of *DeCACHe*, who can insert new or edit existing data, based on the results of exploratory and comparative studies (e.g., [10–12]) that investigate the effects of cognitive factors on varying conditions (e.g., diverse activities, interaction schemes, devices). The inserted data can be entirely new (i.e., create new triples), can build on existing data (i.e., influence existing triples) by numerous ways (e.g., replicated studies, investigation of different factor combinations), or can evolve the relations between the supported factors (e.g., integrate more factors to create n-tuples that influence visit experiences). The aforementioned capability builds the dynamic ecosystem of *DeCACHe* which requires constant flow of data to either build new connections or modify the existing ones.

3.3. Implementation

To implement our tool, we were based on web technologies, aiming to build an accessible and interactive tool. We used various client-side tools, server-side tools, and client–server communication tools, which were built on top of each other and they collectively formed our solution stack. While the scope of this paper is not to provide a detailed overview of the technical aspects of *DeCACHe*, we briefly present the technologies we used: to develop the front-end part, we used the basic technologies of *HTML*, *CSS*, and *JavaScript*, along with various libraries, frameworks, and themes, such as *jQuery* and *Bootstrap*; to develop the server-side tools, we were based on *PHP* and *Apache* server technologies, along with *MySQL* to build the database for the relational representation of the design-space factors; we used *AJAX* to send and retrieve data from the server asynchronously in *JSON* format.

While *DeCACHe* can support a wide range of factors, as long as they are provided within the design-space database, our implementation for the user study supported specific factors. Regarding the activity factor, our implementation supported both *goal-oriented* and *exploratory* visual search activities. In goal-oriented search, the user actively searches for known visual features following a strategy, while in exploratory search, the user scans the environment, usually without following a strategy. Regarding the objective factor, our implementation supported *enhancement of experience* and *improvement of knowledge acquisition*. Regarding the design stage/function, our implementation supported *presentation layer-visualization* and *conceptual design*. Regarding the cognition factor, our implementation supported *Field Dependence-Independence* and *Visualizer-Verbalizer* cognitive styles. Figure 2 depicts two sample screen-shots of *DeCACHe* front-end part.

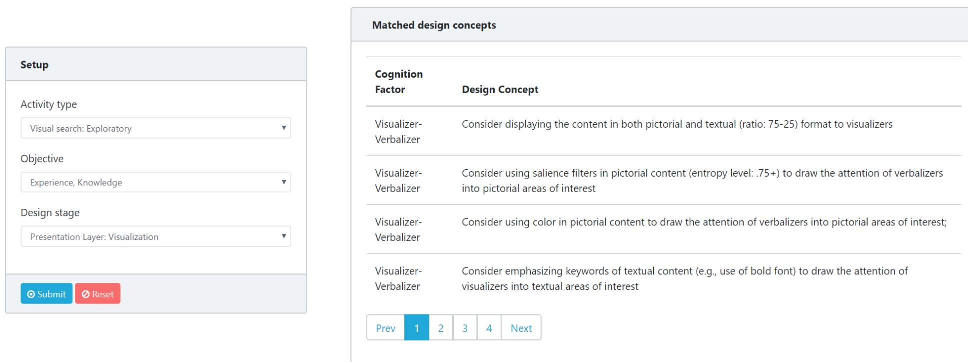

Figure 2. The left panel is used to initialize *DeCACHe* by setting the activity type, the objective(s) and the design stage that the designer wants to apply the personalization scheme on. The right side displays the matched design concepts for a specific cognition factor and under the conditions defined during the setup phase.

4. Evaluation Study

4.1. Method

Overview. The goal of this study was to evaluate the use of *DeCACHe* by professional CH designers. The CH designers used *DeCACHe* to re-design a CH activity (e.g., a CH game) and create personalized versions based on the cognitive profile of the potential users (e.g., museum visitors who play their CH game). Seventeen CH designers used our tool, shared their experiences with us, and we analyzed them following a thematic analysis approach based on the MUSETECH framework [47]. We discuss them in detail in the following paragraphs.

Procedure. The user study was divided into three stages: (i) preparation; (ii) main stage; and (iii) analysis. The preparation started with the recruitment process, during which we contacted CH professionals who had experience in designing CH activities and communicated our study motivation. Next, the CH designers who were willing to take part in the study received more information about the study and we arranged a mutually agreed date and time to conduct the main stage of the study: (i) the participants provided their consent; (ii) we presented our cognition-centered approach [13] and described *DeCACHe*; (iii) the participants used *DeCACHe* to adjust a CH activity and provide alternative versions, which were adaptable to the cognitive characteristics of the users, using any resource they would normally use (e.g., sketching wireframes, drafting a design document) within two hours (Figure 3); (iv) we discussed with the participants their overall experience following a semi-structured interviewing approach in which we adopted the MUSETECH [47] model. During the aforementioned steps, we took notes and recorded the participants when necessary. After all participants completed the main stage, we collected the data, transcribed the recordings, and performed a thematic analysis based on the MUSETECH framework [47], which is discussed in more detail in the following paragraphs.

Participants. We recruited 17 CH designers, who had designed at least one CH activity as CH professionals, meaning that the CH activity was designed to meet the requirements of a CH institution. This was delivered to the CH institution, which, in turn, delivered it to its visitors to interact with the exhibits of the institution. We communicated the study and we recruited the participants by inviting them to a workshop, sending email invitations, directly contacting acquaintances of the research team, and posting call-out flyers on social media pages. All participants were informed about the study and provided their consent for the data collection and analysis by our research team.

CH activities. The participants could either choose to adjust a CH activity that they had designed in the past or they could adjust a CH activity provided by the research team. The provided CH activity was *MuseumScrabble* [48], which is a location-sensitive multiplayer mobile game for museums and it is played by competing players who use their mobile devices to scan museum exhibits and link them to CH themes. The other CH activities were also based on visual search tasks supporting either free exploration (e.g., an augmented museum tour) or goal-oriented tasks (e.g., a virtual CH game with specific sub-tasks that the player should follow to complete a game level).

Thematic analysis. To analyze the responses, we conducted an inductive thematic analysis as outlined by Braun [49]. Our aim was to gain a rich understanding of the overall experience of CH designers when using *DeCACHe* to design personalized CH activities that would adapt to the cognitive profiles of their users. The research team was involved in reviewing the transcribed data, generating the codes and the themes of the analysis, and interpreting the produced data through an iterative discussion process. The inductive thematic analysis resulted in codes (Appendix A) that are complied with the MUSETECH evaluation framework [47], which we discuss next.

Figure 3. A CH designer uses *DeCACHe* to produce alternative sketches for the design of cognition-centered personalized CH activities.

In their recent work, Damala et al. [47] presented MUSETECH framework for evaluating CH technologies (e.g., CH software systems). It is based on three perspectives (CH professional, CH institution, and CH visitor) and four concepts (design, content, operation, and compliance). Each concept is divided into clusters and each cluster has various dimensions. Considering the goal of this study, we focused on the perspective of the *CH professional* and the concept of *design*. The corresponding clusters for our selection (CH professional and design) are: (i) design and product ideation; (ii) experience design; (iii) affordances and metaphors; and (iv) aesthetics. A more comprehensive guide of the evaluation framework is provided by the MUSETECH companion [50].

4.2. Results

In examining the CH designers' experiences when using *DeCACHe*, we focused on the themes discussed in the previous section (i.e., design and product ideation; experience design; affordances and metaphors; aesthetics). Note that the themes are not mutually exclusive. Each theme is discussed below with illustrative quotes, labeled by participant number (e.g., Participant #1); quotes that were not made in English were translated from the original language.

Design and Product Ideation. The study participants had a clear understanding of the design concept and purpose of *DeCACHe*, and thus they were aware of what they could achieve through *DeCACHe*. Considering the novelty of the cognition-centered framework, fleshing out the concept idea to a concrete design proposal is challenging. In our study, we explicitly explained the cognition-centered approach to the participants; however, in real-life scenarios, the description of this approach and what *DeCACHe* offers should be provided to the CH designers through means that do not require the presence of the research team. Towards this direction, tools like video tutorials, visual guides, virtual agents, and bots that could help the designers to get a deep and precise understanding of the cognition-centered approach and its benefits to the end-users (e.g., museum visitors) could be employed. We should also stress the importance of the learning effect, meaning that such tools would benefit the designers the most at the beginning of their interaction with *DeCACHe*, as they would use it more effectively and efficiently after learning to use it:

> " *OK, I have a clear picture of what DeCACHe does and how it works. However, my concern is that it complements an approach that I am not familiar with. Actually, my concern is that how can I suggest it to my co-workers or other designers if I cannot support the background of the framework. I have a clear picture of it because you explained it and it is awesome, but you cannot be always present; it's not effective or even feasible. Thus, why not create some kind of tutorial or an info page that provides a description of the framework? Not the technical details, but why and how it improves the visitors' experience. Thus, the designer will both have a clear picture of it and they will be persuaded to use it.* " ∼ [Participant #11]

According to participants' comments, *DeCACHe* can be used in various stages of the design life-cycle, both during the early stages, where the designers conceptualize the activity and they should have a clear idea of the types of users they should support, and, during the later stages, where the designers apply the concepts to their design process. Several factors contribute to the aforementioned finding, such as the different approaches that professionals follow when designing digitized systems and the format of both *DeCACHe* and the suggested design concepts. In particular, considering that *DeCACHe* is built on common and widely used technologies and that the design concepts are delivered in free textual form, *DeCACHe* does not introduce dependencies that limit the designers' options on how and when to use it. Therefore, *DeCACHe* can be used by CH designers in their preferred way without intervening in their design work-flow:

> " *I really like how DeCACHe is delivered, as it gives the freedom [to me] to use it in any stage [of the design life-cycle]. Actually, you know, we [designers] have our own preferences on when to use a tool to help us with the design or what design process we follow. Thus, I think that DeCACHe doesn't limit our choices and can be used throughout different design approaches.* " ∼ [Participant #4]

> " *I'd definitely not like any intervention [of tools that support design decisions] within my work-flow. Thus, how you deliver it [DeCACHe], is what I'd expect for.* " ∼ [Participant #11]

Regarding the technical knowledge, the participants commented that any designer would have the requisite knowledge of the *DeCACHe* technology, and thus no external contractors or other digital media and information-and-communications technology (ICT) specialists would need to be consulted. However, a concern was raised regarding whether the users of *DeCACHe* would be aware of the cognitive psychology principles that are supported by the tool and how they would be able to apply knowledge that they are not familiar with, especially in scenarios that are vague to them. For example, such a scenario could be when more than one cognition factors are suggested by *DeCACHe*, and thus a user that is not familiar with cognitive psychology might face difficulties in understanding the differences between the suggested factors and in deciding which factor they should follow to build the personalized CH activity upon. In this case, even if *DeCACHe* provides the users with a relativity score (i.e., how relative the suggested cognitive factors are to the selected activity and objective factors), they might wonder how this score is computed and how relevant this score is to the CH activity they design, and thus it could raise trust issues regarding the use of *DeCACHe*. Therefore, more information about the cognition factors should be provided by *DeCACHe* in formats that would help the designers the most to understand them and make the appropriate design decisions based on the cognitive psychology principles. For example, the system could provide a detailed description of a cognitive style and its dimensions, along with examples of good and bad use of their dimensions to deliver meaningful information processing tasks:

> " *Regarding the technology that DeCACHe was built on, I don't think that anyone will face any issues with it. However, the problem is when someone will try to understand the suggested cognitive factor, which will probably be something totally new to a designer who has no clue about cognitive psychology. I think that providing a brief description of the suggested cognitive factor would help the designers to create more meaningful adaptations.* " ∼ [Participant #6]

> " *What happens when the system returns more than one cognitive factors? Which one should someone use? I assume the top one, but why? I mean, how can I be sure which of the returned factors are more suitable in my case? Maybe DeCACHe should provide examples of when and how each returned factor works best.* " ∼ [Participant #13]

Experience design. The study participants welcomed the capability of *DeCACHe* to support CH designers to create tailored content for the end-users, as, through *DeCACHe*, the CH designers are guided to articulate and fine-tune the targeted experience and communicated narratives to different visitors' cognitive characteristics. Therefore, the designed experiences would be more relevant, meaningful, and memorable for the targeted audiences, which is a key objective for both the CH professionals and the CH institutions. As a result, the audience is expected to have a more pleasant visit experience, which would support the goals of the CH stakeholders (e.g., improve knowledge acquisition, improve engagement):

> " *I'm a big fan of personalization because I can deliver to the users what is more meaningful to them, what they prefer, what they feel more natural and comfortable with, etc. Thus, using a supportive tool like DeCACHe will provide me with what I need to better understand my users, better serve them, and help them have a fun experience.* " ∼ [Participant #1]

While personalization is a theme that attracts CH stakeholders and several steps have been made towards this direction during the last years [37], both in research and industry, there is still a major concern about its applicability. This concern mainly results from the lack of available resources (e.g., funds, manpower). While tools like *DeCACHe* rarely have dependencies on other costly services, their adoption to the design life-cycle may increase the cost in terms of man-hours, third-party resources, etc. However, the estimation of the extra cost can be tricky as it depends on several exogenous factors, such as the design stage that the designer applies the adaptive intervention on or the nature of the derived design concept. For example, modifying the mechanics or the concepts of a CH game would probably have an increased cost compared to an intervention that targets content visualization. Therefore, the use of cognition-centered personalization tools should provide design concepts that can be applied through effortless and non-costly interventions, aiming to help CH designers to adopt personalization approaches in their design life-cycle:

> " *[With personalization] you never know what the cost will be, so, while it is attractive to many professionals, I am skeptical about its use; not because of its impact but because of the cost. Let me give you a simple example, let's say that I use DeCACHe and it provides me with 2 design guidelines that I want to follow. The first one is about changing the app interactions, which means that I need to design them from scratch and test them. This will increase the cost on my side, which will also increase the cost for the museum, so the question is: can and will the museum pay for it?* " ∼ [Participant #17]

Moreover, personalization attempts are based on user modeling, which, in our framework [13], is associated with the building of user profiles that match the cognitive characteristics of the visitors. Therefore, there is a need to know the profiles of the CH visitors in order for the CH activity to be adapted to their cognitive profiles. This can be achieved through implicit elicitation of the cognitive profile via various tools, such as classification techniques based on eye-tracking [51] and interaction data [52]. These tools are provided by the cognition-centered framework [13] and they are not part of the main design life-cycle of CH activities. Nonetheless, such tools should be integrable and easily adjusted to fit the context of the activity and be transparent to the user. Therefore, such tools can be provided as services (e.g., web-services) that can be utilized within the CH activity with little development/programming effort:

> " *Let's say that I finalize two versions of my museum guide and the developer builds them. There is a question on how does the application know if a visitor is a visualizer or a verbalizer? This is very important for the feasibility of the adaptation; so I'm wondering, is this something that I should consider during the design stage? I assume not, but I would like to know how this is addressed.* " ∼ [Participant #7]

DeCACHe can help the CH professionals to design more inclusive activities which support the cognitive needs and preferences of people with different characteristics, and thus *DeCACHe* ensures that CH designers do not favor a group of people with specific cognitive characteristics over others. However, this can drive into designs that cause imbalances and not desirable experiences towards other factors, which are important for specific types of activities. For example, creating a balanced CH game regarding the users' cognitive characteristics could imply the modification of game mechanics that influence the competitiveness factor between the players, which is considered as an important factor for the players' experience and engagement [53]. Therefore, the CH designers should be able to critically make design decisions which are in line with the objectives of the activities they design, in order not to introduce problems in other aspects of the activity. Moreover, the interplay and the possible trade-offs between varying aspects of the CH activities should be explored:

> " *DeCACHe will help me create cognition-balanced activities, but what happens with the rest of the attributes that I am concerned with. I build a game for a museum which triggers the competitive nature of the players. If I adjust it with the design guidelines, maybe the game becomes easier for some players and more difficult for others.* " ∼ [Participant #16]

Finally, a discussion point was around whether the use of predefined design concepts limits the creativity of the CH designers. On the one hand, they can lead to CH activities with similar characteristics, which is not a desirable outcome for the majority of the designers. On the other hand, they can trigger the creativity of the designers to implement innovative ways to suitably adjust their activities to follow the derived design concepts. While, in general, it is not mandatory for the designers to follow a specific set of design concepts, we should stress that there is a line between whether a derived concept is a recommendation or a guideline that must be followed, which might not be clear when the designers are involved in projects introducing theories that they are not familiar with, such as cognitive psychology.

Hence, this should be addressed by our tool. In the same line, considering that it is important for a designer to know whether the non-adoption of a recommended design concept would result in poor user experience, *DeCACHe* should provide explicit information about the impact of not following a design concept:

> " *It is not mandatory to follow the recommendations made by any system, but if I choose to follow them, they cannot limit my creativity or my imagination. Contrariwise, I think that they would push me to be even more innovative, as I must find a way to include them in my activity, without jeopardizing the overall experience of the users.* " ∼ [Participant #4]

> " *If all designers follow the same guidelines, which are too strict or too binding, it is more than possible that all activities will have the same characteristics. This is something that I wouldn't prefer either as a designer or as a visitor.* " ∼ [Participant #17]

> " *I am not sure whether the design concepts that DeCACHe delivers are mandatory or optional. Moreover, I would like to have information about the impact of not applying a design concept. Would my users have a negative experience?* " ∼ [Participant #17]

Affordances and metaphors. The terms and metaphors used by a user interface should build a common ground between the users and the functionalities of the user interface. Considering that *DeCACHe* aims to bridge the gap between academic research and practice, the use of proper terminology is critical for avoiding negative connotations seen in the broad domain of human–computer interaction [54] and for improving the efficacy of designers to create meaningful cognition-centered CH activities. This challenge is becoming more intense when considering that it is likely for designers not to be familiar with cognitive theory. Hence, *DeCACHe* should aim to fill that knowledge gap by helping designers in understanding common terms and connections within design and cognitive theory contexts. As a result, *DeCACHe* would make it easier for designers to work through the process and would help them feel knowledgeable about the domain:

> " *I am not sure what the cognition-related concepts mean. I see them for the first time and so I don't understand what you mean by field-dependence, for example. A brief description for people who are not familiar with cognitive styles would be helpful.* " ∼ [Participant #3]

> " *The cognitive factor seems to be like a 'black box' factor that I don't need to know about. However, I think that it would help me if I knew a bit more about the suggested [cognitive] psychology principles.* " ∼ [Participant #6]

Considering that many CH designers follow co-design approaches [55,56], they would welcome the integration of collaborative tools within the environment of *DeCACHe*. Such integration would help people who work with others on the same design project to implement various interactions over the team through a single environment. Such interactions could support the designers to moderate the team, keep track and evaluate the project progress, hold team members accountable for their level of participation and their responsibilities within the team, etc. Moreover, providing effortless integrations of *DeCACHe* with other well-known platforms, such as Slack or Discord, would provide more efficient ways of communicating the cognition-centered design outcomes between different CH stakeholders:

> " *What I miss in DeCACHe is a feature that enables the communication between people who work on the same project. It could be as simple as a plugin for Discord or a more complex tool that enables illustrative co-design.* " ∼ [Participant #14]

Regarding the interface design, the study participants commented that they could easily initialize *DeCACHe* through the step-by-step process, as discussed in Section 3.2. The setup wizard helped them define the design criteria for their activity and initialize the design-support process. Moreover, they navigated to the results without any problems; however, as discussed in previous paragraphs, providing further information about the matched cognitive factors and examples for the recommended design concepts would be helpful:

> " *The GUI is clean, clear, and comprehensive. The process is straightforward regarding the configuration step. The same applies to the results. Maybe a more detailed description of the results is required for users—myself included—who are not familiar with cognition-centered approaches.* " ∼ [Participant #8]

Aesthetics. A thorough discussion about the format of the recommended design concepts took place; the study participants advocated the use of the textual format and they were against the use of other formats (e.g., plugins for specific editors or engines). Considering that designers adopt different tools to create their designs and communicate them to the rest of the project stakeholders, the delivery of the design concepts into technology-dependent formats would discourage the designers from adopting *DeCACHe*, as it would be restrictive and would limit their design options (e.g., use a specific design engine). On the other hand, the textual format was familiar to the designers and was their preferred presentation format of the design concepts, as it gives them the freedom to apply the recommended concepts in the way they feel more comfortable and experienced with:

> " *The textual format is perfect! To be honest, I am not sure whether it is realistic to have guidelines in any other format, such as plugins for Unity because such delivery will be extremely restrictive for a designer. Not all designers use the same tools, and many designers adopt different tools based on the project. Moreover, I am not sure how you could provide other formats as the complexity is high and then DeCACHe would be too complicated to be adopted.* " ∼ [Participant #16]

As discussed, the participants were satisfied with the current presentation of the derived design concepts; however, they recommended various ways to improve it. Their feedback converged into accompanying the text with multimedia resources, such as images. For example, a design concept like "*provide images of 0.75 entropy for verbalizers and images of 0.40 entropy for visualizers*" would be more helpful for the designers if they could also see how an image of 0.75 entropy and an image of 0.40 entropy look like.Moreover, when the design concepts refer to non-common or non-ordinary notions (e.g., image entropy), the designers would benefit from knowing how the proposed concept would be applied, whether a third-party service would be needed, what the extra cost would be, etc. In our previous example, *DeCACHe* should provide the designers with information about how they could assess and modify the entropy level of an image:

> " *The text doesn't say much; actually, it can say much, but I will get bored reading all this text. However, they say that a picture is worth a thousand words. Thus, why not use pictures along with text, to make it easier for the designer to comprehend the design concepts?* " ∼ [Participant #3]

> " *I think that I get the point of the design concept, but how can I apply or measure the entropy? If you could add a visual paradigm or give a link with more info, it would help me a lot.* " ∼ [Participant #8]

Examples with good and bad practices regarding the adoption and the implementation of the derived design concepts would also be welcomed. Considering that many designers are not familiar with the cognitive theory principles supported by *DeCACHe*, the illustration and the explicit description of good and bad choices would help them make more effective design decisions. Hence, through visualizing successful and unsuccessful applications of the design concepts, we anticipate that we will increase the efficacy of *DeCACHe* and eventually the designed activities would fit better the cognitive preferences and the needs of the end-users:

> " *A section with things 'to do' and things 'not to do' [along with the design concepts] would definitely help me to be more precise on how to accomplish what I want to accomplish.* " ∼ [Participant #9]

> *" Some people say that you learn more from bad examples than from best practices, and I truly believe it. Thus, my suggestion is to see in DeCACHe bad examples of a recommendation and why they are considered bad, in order for me to know what I should avoid. "* ∼ [Participant #14]

The study participants commented on the language used for the design concepts, and they stated that they would prefer them to be in a language that is more direct, not formal, with a more personal and engaging tone. As a result, the designers would have a straightforward picture of the recommendations and they would feel more confident about the desired outcome of the cognition-centered design concepts. Moreover, the recommended concepts could be presented as 'lenses' or check-lists to help the designers keep track of what they have followed and better evaluate their design process. Furthermore, profiling and project-related functionalities, which keep track of users' preferences and actions, could be added to *DeCACHe*, aiming to save time and effort from CH designers for their future cognition-centered CH projects:

> *" You don't need to be too formal when presenting the recommended concepts. I'd prefer a more direct language, so I can have a clear picture of what DeCACHe recommends; otherwise, it [the design concept] can be ambiguous and its interpretation depends on how each designer understand it. "* ∼ [Participant #14]

> *" I'd prefer to have a set of questions that I should answer, like in 'The Art of Game Design: A Book of Lenses", as this would help me to evaluate my design process regarding the integration of cognition-centered principles and identify what else I need to work on. "* ∼ [Participant #17]

Finally, regarding the look-and-feel of *DeCACHe*, the participants were familiar with it, given that it was based on well established and commonly used technologies and resources (e.g., plugins, templates). However, they would prefer to have more options regarding the visual appearance of the tool in order to adjust it to their preferences. Therefore, a level of personalization is required in order for the designers to meet their requirements, such as the common terminology, which discussed in the previous section. As a result, we anticipate that the tool will be more accessible and have a wider acceptance by CH designers with diverse needs and preferences, and thus it would improve the effectiveness of the cognition-centered design process:

> *" The aesthetic part of DeCACHe is fine, as it follows the trends and it is usable. I'd like to have more options to configure it a bit, such as change the background colors or 'day and night versions', which can also improve the accessibility of your tool. However, they are not of major importance, as long as the tool remains functional and reliable. "* ∼ [Participant #3]

5. Discussion

5.1. Supporting Cognition-Centered Design Decisions with DeCACHe

Seventeen professional CH designers verified the suitability of *DeCACHe* for designing cognition-centered adaptive CH activities during the early stages of the design work-flow. They assessed positively both the format of the tool and the presentation of the recommended design concepts. In particular, the tool did not require forced interventions within the designers' work-flow; thus, the designers felt more comfortable and free to adopt it during the design stages that they felt it was necessary to be used throughout the design life-cycle. Similarly, the delivery of the design concepts in free textual forms rather than technology-dependent pre-defined collections ensured that they could be adopted by a wider group of CH designers who could apply them within their projects with no further restrictions.

However, our study findings revealed that there is still room for improvement and new features can be supported by *DeCACHe*. There is a need for helping *DeCACHe* users, who are not familiar with cognitive theory, to understand the cognitive principles supported by *DeCACHe*. By configuring *DeCACHe* to introduce cognitive theory to the designers (e.g., through tutorials, brief description of cognitive factors, examples of good and bad practice), we would help them to build a more concrete and solid understanding of the underpinned theory, and thus the designers would be able to make more substantial design decisions that fit the cognitive profiles of their users. With such support mechanisms, *DeCACHe* could also help CH designers to create activities that do not lead to imbalances between the end-users because of misconceptions or because of not following a design concept with high impact. Moreover, *DeCACHe* could be integrated with collaborative tools to support co-design approaches and it could provide alternative means for presenting the design concepts (e.g., textual format along with multimedia resources) to help designers make better and more accurate cognition-centered design decisions. By refining and fine-tuning *DeCACHe* with the integration of such features, *DeCACHe* will be able to better support CH professionals in making effective and efficient design decisions regarding their cognition-centered activities.

5.2. Integrating Principles from Cognitive Theory in DeCACHe

Focusing on the cognitive theory principles, *DeCACHe*, in its current implementation, supports specific cognitive factors (e.g., Field Dependence-Independence and Visualizer-Verbalizer cognitive styles), types of CH activities (e.g., goal-oriented and exploratory visual search tasks), and objectives (e.g., improve knowledge acquisition, enhance user experience). Despite the fact that the supported cognition, activity, and objective factors are common in the CH domain [9,11,13], there is a need to provide more factors by enriching the design-space of *DeCACHe* and strengthening the relationships between the varying entities. This can be achieved through exploratory studies, which aim to investigate the interplay effects of diverse triples of the aforementioned factors, and, through comparative studies, which aim to investigate what personalization interventions have a major impact on these factors. For example, a future exploratory study could be the investigation of the effects of different auditory cognitive styles on content comprehension when using audio museum guides; a comparative study could be the measurement of the effect of different auditory-centered interventions on the comprehension of the tour exhibits by the visitors.

Considering that the architecture of *DeCACHe* provides means to include design concepts that derive as rule-based transformations from the results of studies like the aforementioned ones, we move towards an inclusive design model which underpins cognition-centered paradigms. We envisage an open access repository that can be used by the research community to deliver cognition-centered rules, which would derive from the results of exploratory and comparative user-studies. Through such a collective repository, both the CH designers and the end-users (e.g., museum visitors) would benefit. The CH designers would have access to a dynamically improved and enhanced context in which they would create CH activities that fit best to their objectives and the cognitive profiles of their end-users, who would be delivered activities tailored to their cognitive preferences and needs, which we anticipate to enhance their visit experience.

5.3. Complementing the Cognition-Centered Framework with DeCACHe

As discussed in Section 3.1, *DeCACHe* is part of a personalization framework for delivering cognition-centered adaptive CH activities [13]. *DeCACHe* is intended to be used by CH designers to create such activities, tailored to the end-users' cognitive profile. While it can be used as a standalone tool, the overall cognition-centered approach requires the employment of the other components of the framework (e.g., content creation, visitors' profiling in run-time, dynamic adaptation of CH activity) in order for the CH professionals to provide meaningful experiences to the end-users. We should stress that *DeCACHe* covers the pre-visit aspects of a CH experience, while the during- and post-visit aspects are managed by other framework components, such as the adaptation engine and the experience sharing mechanisms.

The CH domain is a multidisciplinary domain which attracts professionals with varying backgrounds from different fields. Leveraging the architectural model of *DeCACHe*, we could adopt it and design other components of the cognition-centered framework that can be used by other CH stakeholders. For example, content providers could use a tool, which would be equivalent to *DeCACHe* that would provide them with an authoring environment enabling them to create content for CH exhibits under the design concepts recommended by *DeCACHe* (e.g., use text and image with a 75:25 ratio for visualizers). Moreover, considering that *DeCACHe* is based on cognitive modeling of the CH visitors, it is important to support the elicitation of the visitors' cognitive profiles through a transparent and dynamic approach. Several techniques can be employed in this direction, such as user modeling through the analysis of gaze and other interaction data, as recent studies [13,51,57] have shown that they can be used to elicit cognitive factors with high accuracy, transparently to the user, with no human intervention, and in run-time, during the early stages of a visual search activity.

Therefore, *DeCACHe* not only complements the cognition-centered framework for delivering personalized CH activities [13], but it also provides the grounds for the design of other framework components. The combination and the cooperation of these framework components would build a cognition-centered ICT environment which could be used by CH stakeholders to create CH activities that are tailored to the cognitive preferences and needs of their end-users (e.g., museum visitors), and thus delivering them with enhanced visit experiences.

5.4. Combining Cognition with Other Personalization Factors

The architectural models of *DeCACHe* and the cognition-centered framework not only support the complementation with other components, as discussed in the previous section, but also support the integration of other personalization factors besides cognition. Such factors reflect on various aspects that influence the visitor experience [58,59] such as intrinsic motivations [60], perceived quality of the CH experience [61], and emotional connection [62]. Personalization factors that can be used in combination with cognition are: visitor location [63], interests [64], social behavior [65], background knowledge [66], preferences [67], motivation [68], themes [69], mood [70], visiting style [71], visit and viewing time [72], visit history [73], and disabilities [74]. Therefore, we envisage an open collection of personalization factors that could be integrated in *DeCACHe* and could be used as complementary factors to cognition, aiming to provide the CH designers with an enriched toolset to help them make better design decisions when creating personalized CH activities.

5.5. Implications beyond the CH Domain

To the authors' knowledge, *DeCACHe* is the first attempt for supporting CH designers in creating cognition-centered adaptive activities. While *DeCACHe*, in its current implementation, aims to support designers within the CH domain, it could be expanded to other domains, where there is evidence that cognitive characteristics have an impact on the users' experience, such as e-learning [75], gaming [76], security [77], business and management [78], and e-commerce and marketing [79]. For example, in their recent work, Katsini et al. [80] revealed that individuals who are characterized as field-dependent tend to have a more limited password key-space compared to individuals who are characterized as field-independent when creating a graphical password. As a result, field-dependent individuals tend to create weaker passwords than field-independent individuals. By using a tool like *DeCACHe*, the designer of the authentication mechanism would leverage the unique characteristics of field-dependent and field-independent users and would provide adaptive interventions that favor both types regarding the password creation process. Therefore, the approach followed to design *DeCACHe* verifies and improves the external validity of our research attempt, and thus we anticipate that building similar tools will support designers of diverse domains in creating personalized activities tailored to the domain-specific context and the cognitive profile of the end-users.

6. Limitations, Future Work, and Ethical Considerations

6.1. Limitations

For the scope of our study, the CH designers used *DeCACHe* during the early stages of the CH design life-cycle, without having the final CH system fully implemented. In particular, while they used *DeCACHe* to design the CH activities, the produced activities were not further developed (e.g., as functional prototypes or final products) and were not delivered to the end-users (e.g., museum visitors). We believe that this did not affect their experience, as the CH designers followed their standard design approach, but we believe that we would gain more insights about the effect of the use of *DeCACHe* if we could investigate it throughout the full life-cycle of a CH product (e.g., design, development, testing). Moreover, depending on the working conditions of the CH designers (e.g., individually or as members of a larger team), more professionals could be engaged within the CH activity life-cycle. For example, visual and graphic designers are employed to communicate design decisions visually, and their involvement in the CH activity life-cycle could result in iterative "give-and-take" processes between them and the CH designers. Furthermore, some design studios encourage the adoption of co-design and participatory techniques, and thus more than one people serve as designers. Hence, the collaboration between different designers using *DeCACHe* in the same project is an interesting research dimension, which we did not investigate in this paper. Moreover, we should stress that, from the end-user perspective, our work focused only on the cognition factor; however, in collaborative and/or competitive contexts, which are common in the CH domain (e.g., collaborative CH games [81]), more factors can influence the user experience besides cognition [82], such as emotional involvement and collective intelligence [83], which should be investigated.

Another limitation of the presented work is that the CH designers used *DeCACHe* for first time, and thus we did not take into consideration possible effects of the learning curve in our analysis. By investigating the use of *DeCACHe* in a long-term study (e.g., a designer uses *DeCACHe* multiple times during the design cycle), we would gain deeper insights about its practical usage in real-life conditions.

Moreover, we should stress that the CH designers used a *DeCACHe* version that had been designed with limited evaluation process. Based on the designers' feedback, *DeCACHe* should be refined to meet the requirements pointed by the designers and better support them during the design decision-making process. Finally, *DeCACHe* design-space is limited to cognition factors that have been explored by our research team in varying CH contexts, and thus there is room for enriching the design-space with more cognition factors. However, we should stress that the work presented in this paper is a first step for creating a recommendation mechanism for CH designers to help them make better design decisions when considering cognition as a design factor. More studies are needed to fully explore the capabilities of *DeCACHe* during a complete CH design life-cycle.

6.2. Future Work

Based on the discussion of the study results and limitations, our immediate future steps consist of (i) refining *DeCACHe* by introducing features that derived from the CH designers' feedback; (ii) further evaluating *DeCACHe* by engaging more CH professionals in diverse conditions (e.g., co-design scenarios) to create cognition-centered personalized CH activities of varying characteristics; (iii) integrating *DeCACHe* as part of the cognition-centered framework for delivering personalized CH activities, (iv) completing a full CH system life-cycle, which will involve various CH professionals (e.g., CH designers, visual designers, content providers) in the various stages of the CH system life-cycle; (iv) assessing the effect of cognition-centered personalization by performing a large-scale user-study in real-visit scenarios where the visitors of a CH site will use a cognition-centered personalized version of a CH system; (v) investigating factors that influence co-design and collaborative experiences and enriching the framework with them; (vi) enriching *DeCACHe* by providing collections that combine cognition with other personalization factors, such as end-users' interests.

6.3. Ethical Considerations

Our research incorporated appropriate consideration of ethical issues into the design, the conduction, and the analysis of the user-study. Our research involved interaction with human subjects, and it was performed following context-specific ethical guidelines. Researchers actively respected the human rights and dignities of all those involved in the studies and appropriately addressed questions of consent, capacity, power relations, deception, confidentiality, and privacy. All CH designers participated voluntarily in our studies, and they all agreed to and signed a consent form that their interactions with *DeCACHe* would be recorded and analyzed anonymously as part of experimental user studies of our research group. The study participants could bring the experiment to an end at any time and for any reason. During the experiment, the researchers had the authority to bring it to an end, if there was probable cause to believe that it could harm the participants in any way. All participants were informed about the experimental procedure and the rights they had as volunteers. However, no further details about the aim of the studies were provided to them to avoid bias effects.

7. Conclusions

In this paper, we extended our preliminary work [84] and presented *DeCACHe*, which is a tool that complements our personalization framework [13] and supports designers in creating personalized CH activities that leverage the visitors' cognitive characteristics. Along with the design of the tool, we reported a user study with seventeen professional CH designers who used *DeCACHe* to create CH activities tailored to the cognitive characteristics of their potential users. We evaluated *DeCACHe* following the MUSETECH [47] approach and analyzed the CH designers' experiences according to four identified themes: (i) design and product ideation; (ii) experience design; (iii) affordances and metaphors; and (iv) aesthetics. The results revealed that, while there is still room for improvement, *DeCACHe* would be adopted by professional CH designers as a supportive environment which would help them to make better design decisions aiming to support CH institutions' visitors with different cognitive characteristics when they perform cognition-centered personalized CH activities.

Author Contributions: Conceptualization, G.E.R. and N.A.; Data curation, G.E.R. and C.S.; Formal analysis. G.E.R. and C.S.; Investigation, G.E.R.; Methodology, G.E.R., C.S., and N.A.; Project administration, G.E.R. and N.A.; Resources, G.E.R., C.S., and N.A.; Software, G.E.R.; Supervision, G.E.R. and N.A.; Visualization, G.E.R.; Writing, G.E.R., C.S., and N.A.

Funding: This research received no external funding.

Acknowledgments: We would like to thank all those who participated in the study; we really appreciated their willingness to share their experiences with us.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

DeCACHe	Design of Cognition-centered Adaptive Cultural Heritage activities
CH	Cultural Heritage
DS	Design Stage
DF	Design Function
DC	Design Concept
AF	Activity Factor

OF	Objective Factor
CF	Cognition Factor
DCp	Design Principle
DCg	Design Guideline
DCh	Design Heuristic

Appendix A. Guide for Covering MUSETECH Design Aspects for CH Professionals

During the interview with the study participants, we aimed at covering the dimensions of the design clusters of the MUSETECH framework for CH professionals. We list these dimensions below; a more comprehensive presentation of them is provided by the MUSETECH companion [50].

Design 1: Design and Product Ideation.

1. Design concept;
2. Integration with the exhibition;
3. Integration with other Information and Communications Technology (ICT);
4. Balance of physical with digital;
5. Clear understanding of the fabrication process;
6. Level of in-house technical knowledge.

Design 2: Experience Design and Narratives.

1. Experience added value;
2. Relevance to audience;
3. Tailored content;
4. Attentional balance;
5. Social Interaction;
6. Before and after the visit support.

Design 3: Interactions, Affordances, and Interaction Metaphors.

1. Quality of affordances;
2. Suitability of interaction metaphors;
3. Interface design;
4. Clarity of navigation;
5. Follow-up usage on other platforms;
6. Multisensoriality.

Design 4: Aesthetics and Look-and-Feel.

1. Look and feel (materials, textures, colours, weight).

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