The Impact of Knowledge Type as a Contextual Factor on Resource Modality Selection During Initial Stages of Web Search

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ii. Abstract

This dissertation investigates whether the type of knowledge (sensorimotor-procedural, cognitive-procedural, causal-conceptual, relational-conceptual) serves as a contextual factor that influences the likelihood of selecting a search result with a specific modality during the initial search phase. In this context, modality refers to the specific format of the resource in which information is presented on search engine result pages, such as videos, images, or websites. Three experiments, each employing different operationalizations, demonstrated that the type of knowledge significantly influences modality preferences. Furthermore, the study highlights that the decision goes beyond the classical classification of knowledge dimensions (procedural, conceptual) and is further influenced by the extent of spatiotemporal changes involved in the task. The findings suggest that expected spatiotemporal changes could be critical in predicting preferred search result modalities. However, preferences varied for tasks with minimal spatiotemporal changes, particularly in more realistic settings. These insights enrich the discussion of learners' search strategies within theoretical frameworks and suggest that the type of knowledge should be considered as a contextual factor and modality as a resource factor in web searches. Overall, this dissertation provides new insights into the interaction between types of knowledge and search modalities and offers directions for future research as well as potential improvements in search engine design to enhance user experience and the efficiency of information retrieval.

iii. Zusammenfassung

Diese Dissertation untersucht, ob der Wissenstyp (sensorimotorisch-prozedural, kognitiv-prozedural, kausal-konzeptuell, relational-konzeptuell) als kontextueller Faktor die Wahrscheinlichkeit beeinflusst, ein Suchergebnis mit einer bestimmten Modalität in der initialen Suchphase zu wählen. Modalität bezieht sich in diesem Kontext auf das spezifische Format der Ressource, in dem Informationen auf Suchmaschinenergebnisseiten präsentiert werden, wie Videos, Bilder oder Websites. Drei Experimente, die jeweils unterschiedliche Operationalisierungen verwendeten, zeigten, dass der Wissenstyp die Modalitätspräferenzen signifikant beeinflusst. Darüber hinaus hebt die Arbeit hervor, dass die Entscheidung über die klassische Klassifizierung der Wissensdimensionen (prozedural, konzeptuell) hinausgeht und weiter durch das Ausmaß der spatiotemporalen Veränderungen beeinflusst wird, die in der Aufgabe enthalten sind. Die Ergebnisse deuten darauf hin, dass erwartete spatiotemporale Veränderungen ein kritischer Faktor bei der Vorhersage bevorzugter Suchergebnis-Modalitäten sein könnten. Allerdings variierten die Präferenzen bei Aufgaben mit minimalen spatiotemporalen Veränderungen, insbesondere in realistischeren Umgebungen. Diese Erkenntnisse bereichern die Diskussion über die Suchstrategien von Lernenden innerhalb theoretischer Rahmenwerke und legen nahe, dass der Wissenstyp als kontextueller Faktor und die Modalität als Ressourcenfaktor in Websuchen betrachtet werden sollten. Insgesamt liefert diese Dissertation neue Einblicke in die Interaktion zwischen Wissenstypen und Suchmodalitäten und bietet Richtungen für zukünftige Forschung sowie potenzielle Verbesserungen im Design von Suchmaschinen, um die Benutzererfahrung und die Effizienz der Informationssuche zu verbessern.

iv. List of publications

Published manuscripts

Pardi, G., Hienert, D., & Kammerer, Y. (2022). Examining the use of text and video resources during web-search based learning—a new methodological approach. *New Review of Hypermedia and Multimedia*, *28*(1-2), 1–29. https://doi.org/10.1080/13614568.2022.2099583

Pardi, G., Gottschling, S., Gerjets, P., & Kammerer, Y. (2023). The moderating effect of knowledge type on search result modality preferences in web search scenarios. *Computers and Education Open*, *4*, 100126. https://doi.org/10.1016/j.caeo.2023.100126

Pardi. G, Gottschling, S., & Kammerer, Y. (2024). The influence of knowledge type and source reputation on preferences for website or video search results. *Journal of the Association for Information Science and Technology, 75*(5), 521-537. https://doi.org/10.1002/asi.2477

v. Contributions

The contributions of the PhD student (and all co-authors) to the publications and manuscripts that are part of this cumulative dissertation can be found in the following tables:

Author	Author position	Scientific ideas %	Data generation%	Analysis & interpretation %	Paper writing %
Georg Pardi	1	50 %	55 %	50 %	50%
Daniel Hienert	2	25 %	35 %	30 %	25 %
Yvonne Kammerer	3	25 %	10 %	20 %	25 %
Title of publication:		Examining the Use of Text and Video Resources During Web-Search Based Learning – A New Methodological Approach			
Status in publication process:		Published			

Author	Author position	Scientific ideas %	Data generation %	Analysis & interpretation %	Paper writing %
Georg Pardi	1	60 %	65 %	60 %	60 %
Steffen Gottschling	2	10 %	15%	15 %	20 %
Peter Gerjets	3	10%	0 %	5 %	0 %
Yvonne Kammerer	4	20 %	20 %	20 %	20 %
Title of publication:		The Moderating Effect of Knowledge Type on Search Result Modality Preferences in Web Search Scenarios			
Status in publication process:		Published			

Author	Author position	Scientific ideas %	Data generation %	Analysis & interpretation %	Paper writing %
Georg Pardi	1	60 %	65 %	60 %	60 %
Steffen Gottschling	2	10 %	15 %	25 %	25 %
Yvonne Kammerer	3	30 %	20 %	15 %	15%
Title of publication:		The Influence of Knowledge Type and Source Reputation on Preferences for Website or Video Search Results			
Status in publication process:		Published			

1 Introduction

In today's digital age, seeking new information has become synonymous with using the Internet and its search engines (e.g. Sparrow et al., 2011) because they facilitate quick and effortless information retrieval (Câmara et al., 2021). Consequently, using search engines is embedded in our daily routines (Hillis et al., 2012), and search engines have become an essential part of '*an active and critical process of knowledge building*' (Mason et al., 2010, p. 629), regardless of the kind of information we seek. Since searching for information has become so essential and integrated into our daily lives, it is crucial to understand how search processes are conducted and how they differ. By better understanding these processes, we can influence search behaviour through scaffolding measures and inform the design of search engines and AI assistants (such as ChatGPT or Microsoft Copilot) to achieve more adaptive and successful searching. Since web searches are ubiquitous today and occur in various settings and fields of acquirable knowledge, breaking down the search process and making it systematically investigable is worthwhile. One approach is to differentiate the types of knowledge sought. Specifically, knowledge is often categorized into factual, conceptual, procedural, or metacognitive knowledge dimensions (Anderson et al., 2014). Learners widely use web searches, whether they seek information for a procedural, a conceptual or a factual task. Further, it does not seem to play a role in starting a web search whether learners seek, e.g. procedures without spatiotemporal information (e.g., programming) or information about a procedure involving visual real-life observations, including spatiotemporal changes (e.g., tie a knot). In both scenarios, web searches are valuable for accessing relevant information about these subjects. Although both cases involve the search for procedural knowledge, the degree of visually perceivable information assumed differs between the tasks. Hence, it seems helpful to further divide knowledge dimensions by categorising them into types (e.g. van Genuchten et al., 2012) based on the degree of spatiotemporal changes (Tversky, 2005b). This finer-grained approach enables a more detailed investigation of the impact of different knowledge characteristics (i.e., knowledge dimensions and types) on web search behaviour.

This dissertation argues that the knowledge sought can be further categorized in terms of the degree of spatiotemporal changes expected. This modification is also linked to the evolving landscape of search engines, which have excelled in the traditional format of '10 blue links'—a layout where search results and SERPs predominantly comprised text-based components (URL, title, abstract). Instead, search results now differ in structure and design, integrating elements such as images or video thumbnails (Arguello, 2017; Azzopardi et al., 2018; Kammerer et al., 2018; Wopereis & van Merriënboer, 2011). Hence, also search results can be differentiated by their modality, based on whether they mainly offer textual information (often combined with images) or videos (e.g., from YouTube; Feierabend et al., 2021; Smith et al., 2018). As such, structural changes of SERPs reflect the increased diversity in resource modalities. While the kind of information sought (factual, conceptual, procedural or metacognitive) can be seen as a contextual factor of the information seeking process, the kind of modality of information source (being visually implied on the SERP) can be seen as a resource factor of web search (Lewandowski & Kammerer, 2021).

However, despite the increasing complexity of web searches, existing models still describe generic steps of the information-seeking process. They do not consider the knowledge types or the modality of search results as factors. The generic steps are often summarized as defining the information problem, searching and identifying potential sources, evaluating and assessing the gathered information, delving deep into the information for thorough comprehension, and finally, organising and presenting the acquired knowledge (Brand-Gruwel et al., 2005; Kiili et al., 2018; Vakkari, 2005, 2016). The differentiation of steps lacks detail on how users' knowledge seeking behavior and the diversity in search result modality (beyond text-based elements) influence the search process and how these two factors interact.

This dissertation focuses on the central question: How does the type of the sought knowledge, functioning as a contextual factor in web searches, combined with the variety of search result modalities, serving as a resource-based factor, influence learners' search behaviors? This question is particularly pertinent in the context of the initial stages of web searching, explicitly focusing on the learners' selection of an initial search result.

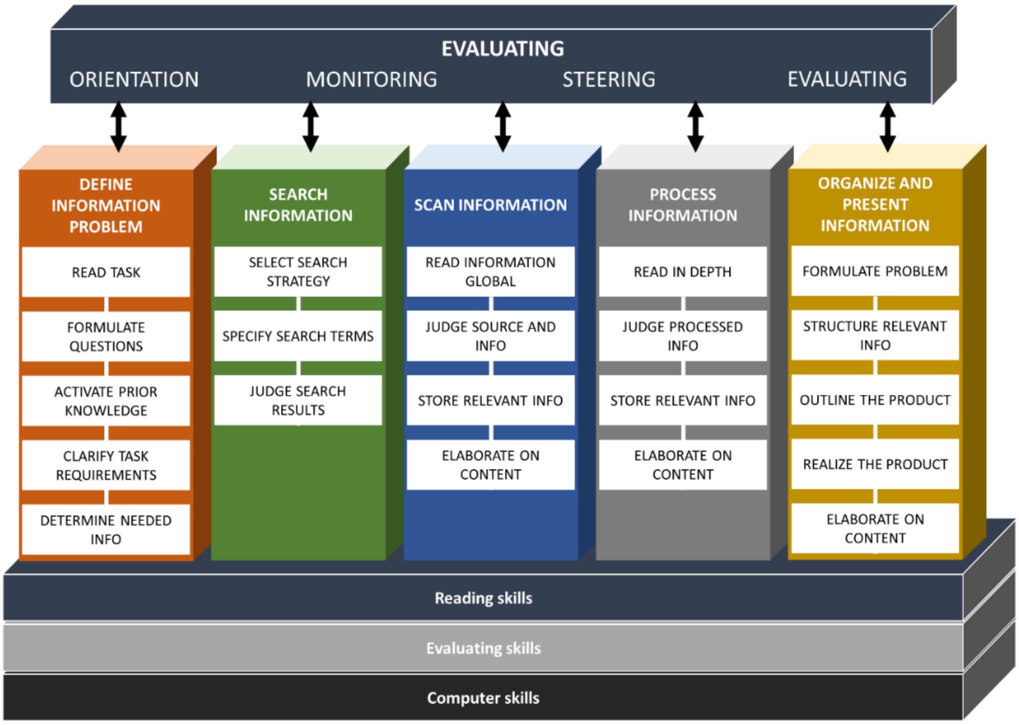
1.1 Theoretical models of web search

People seeking information in digital environments is not a recent development and has already been investigated, for example, in information and library studies (e.g., Kuhlthau, 1991). In her description of the Information Search Process (ISP), Kuhlthau outlines a model comprising six stages (initiation, selection, exploration, formulation, collection, and presentation) through which searchers navigate, experiencing a range of emotions, thoughts, actions, and tasks that vary by stage. However, the definition proposed by Gary Marchionini (1995) is frequently adopted in the context of internet-based information retrieval, predominantly via search engines. Marchionini characterizes information seeking as a form of problem-solving, requiring the recognition and interpretation of the underlying information problem, the formulation of a strategic search plan, the execution of the search itself, and the subsequent evaluation of the results. All the steps described can be iterated through the complete information seeking process (Marchionini, 1989). In this definition, it becomes clear that searching for information generally is a complex process consisting of various recursive sub-processes (Marchionini & White, 2007).

Consistent with this view, most theoretical models concentrating on searching and learning with the internet (e.g. Brand-Gruwel et al., 2009; Broder, 2002; Kiili et al., 2018; von Hoyer et al., 2022; Walraven et al., 2008) follow this structure and describe overarching steps and substeps users pass through on different detail levels or with different focal points. The 'Information Problem Solving while using the Internet (IPS-I)' model, developed by Brand-Gruwel and colleagues (Brand-Gruwel et al., 2005, 2009; Walraven et al., 2008), is a recognized and widely applied model for understanding web search in the context of learning. This model (see Figure 1) articulates five main steps for resolving an information problem: defining the information problem, searching for information, scanning the retrieved information, processing the selected information, and organizing and presenting the gathered information. These steps are supported by the learner's competencies in reading, evaluation, computer skills, and the ability for self-regulation (Brand-Gruwel et al., 2009), which are recognized as individual factors influencing the process.

Figure 1

Information Problem Solving while using the Internet (IPS-I)- Model based on Walraven et al. (2008) *and Brand-Gruwel et al.* (2009)



Over the past years, the process of finding and learning from online information has been further interpreted through a model introduced by Kiili and colleagues (2018). Building upon existing theoretical frameworks, this model was validated through a study with 426 sixth graders, employing confirmatory factor analysis. The primary objective was to refine the component structure of a theoretical model dedicated to online research focusing on text comprehension. The model proposes six integral factors: a) locating information via search engines; b) assessing the credibility of found information; c) verifying the credibility of the information; d) identifying the main idea from a single online resource; e) integrating information from multiple online resources; and f) articulating a well-substantiated, source-based stance. While emphasizing text as the principal information source, the model does not address using different modalities during the search process. In general, the first step of using a search engine is rather imprecisely described. Additionally, it does not specify the types of knowledge sought; instead, it presents a more generalized approach to online information search and learning processes.

A notable limitation shared by both Kiili's model (2018) and the IPS-I framework (Brand-Gruwel et al., 2005, 2009; Walraven et al., 2008) is their lack of deeper consideration for additional factors, such as individual, contextual and resource factors. This aspect, initially proposed by Lazonder and Rouet (2008) and subsequently reinforced by Lewandowski and Kammerer (2021), could be critical for a comprehensive understanding of web search processes. The following section will introduce these factors, particularly emphasizing contextual and resource variables.

1.2 Individual factors

According to Lazonder and Rouet (2008), individual factors are general characteristics of the learner (e.g. language skills or cognitive abilities) and prior domain knowledge. Further, Lewandowski and Kammerer (2021) list age, beliefs about the Web as a knowledge resource, gender, and computer experience as examples of individual factors potentially influencing the search process. Different researchers have shown the influence of such factors on the search. For example, Bilal and Gwizdka (2016) found that different reading and fixation behaviours during web searches varied depending on age. Also, Xing et al. (2022) investigated how age differences influence the search process with spoken conversational search agents. They found that older participants made more requests, and their search queries were longer than those of younger participants. Concerning cognitive abilities as individual factors, Pardi et al. (2020) found that participants working memory capacity and reading abilities were positively related to better learning outcomes within an open web search. This brief introduction aims to shed light on individual factors. However, this dissertation will not explore these factors in depth, as its primary focus lies in examining modality as a resource factor and knowledge type as a contextual factor.

1.3 Resource factors

Resource factors relate to the actual presentation and accessibility of information and search results to the searcher, potentially influencing the search process. Therefore, all factors related to the amount and type of information offered and how to access and find that information are categorised as resource factors by Lazonder and Rouet (2008). As examples, Lewandowski and Kammerer (2021) more generally list the type of device (desktop vs mobile), the search engine results page (SERP) design (e.g., list vs grid), and search result ranking as potential resource factors.

Regarding SERP design, Kammerer and Gerjets (2014) showed that positioning and presenting search results on a SERP in a list or grid design influences selection and search behaviour. They found that a list design led to a more heuristic evaluation of search results compared to the presentation in a grid design. While in a list, users relied mainly on the position of a search result, in a grid design, searchers relied more on valuable cues (such as the name or type of the site) within the search results.

Beyond the design of SERPs (e.g. Gritz et al., 2023) or the presence of sponsored or vertical search results (e.g. Chen et al., 2015), other factors specific to search results can play a role and influence search behaviour and outcomes. Maxwell and colleagues (2017), for example, investigated how the length and informativeness of search result snippets, as a resource factor, influence search behaviour, performance, and user experience on the SERP. While participants generally preferred more extended snippets and perceived them as more informative, the researchers found that more extended snippets do not necessarily improve performance in identifying relevant resources, indicating a tension between perception and performance that must be considered when designing search results. Concerning the effect of including explanations of search result ranking next to search results, Ramos and Eickhoff (2020) showed that even simple ranking explanations enhance user intuition and trust towards the search results. However, this did not increase the overall likelihood of search success but did lead to significant efficiency gains, such that participants found relevant search results faster.

Another addition to search results as a resource factor can be the inclusion of social annotations implemented into search results or the SERP. Muralidharan and colleagues (2012) investigated within two studies how the presence of social cues, for example, the information if someone liked or shared the information, affects the selection of search results. Surprisingly, and counterintuitive to previous research (cf. Kammerer et al., 2009), the results showed that subjects did not directly benefit from social annotations. This study explained this finding regarding the specialized attention patterns during the search, including a focus on titles and URLs, a top-to-bottom reading order of snippets, and the effect of inattentional blindness, causing existing social annotations to go unnoticed.

Beyond the examples already established as resource factors in this context, in the following section, this dissertation will introduce the concept of 'modality' as a crucial resource factor that can directly interact with the search.

1.3.1 Modality as a resource factor

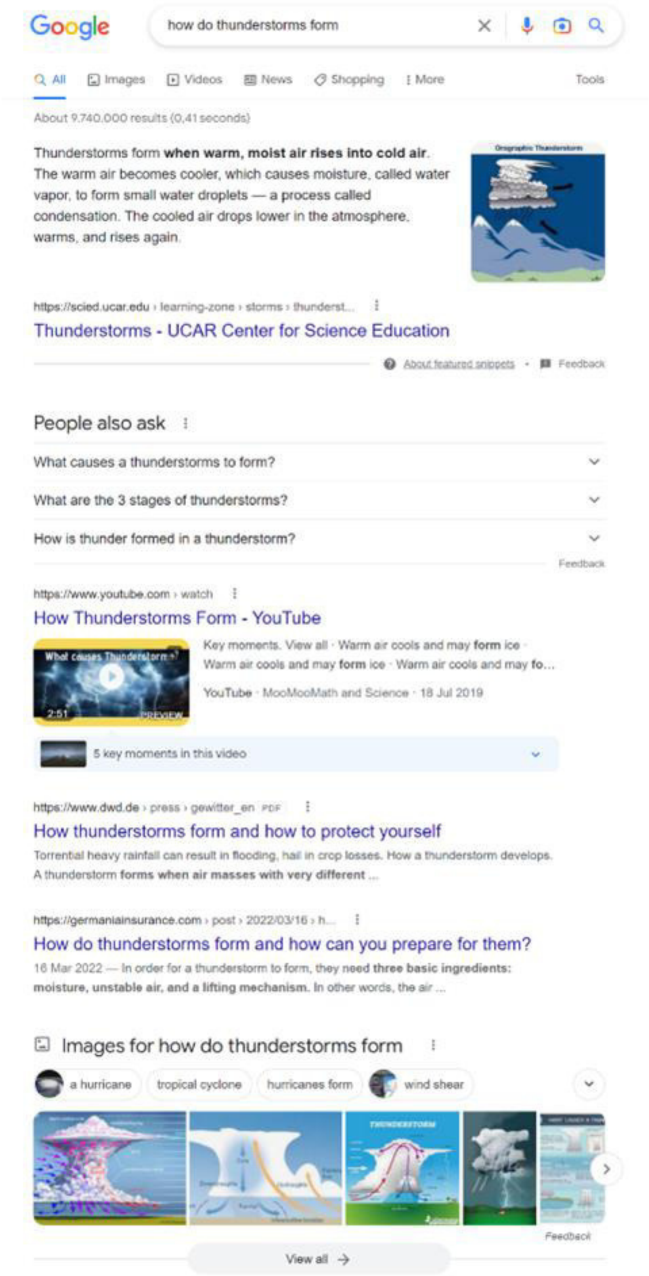
In the context of this dissertation, modality refers to the specific format that represents how access to information is offered on search engine result pages, whether leading to a video, image, or website. Search result snippets shown on SERPs (see. Figure 2) often indicate the underlying resource format and can thus play a central role in the initial selection decision, thereby influencing search behaviour. It is important to note that this usage of the term 'modality' conflicts with its common interpretation in psychology and human-computer interaction. In psychology, 'modality' typically refers to the sensory or memory channel—such as vision or audio—used to process information (e.g. Mayer, 2017). Additionally, the term 'codality' appears in this context, referring to the types of signs (e.g., symbolic-abstract, numerical, pictorial) employed to convey information (Scheiter et al., 2018). While the terms 'multimedia' or 'codality' may arguably be more suitable, this dissertation adopts the term 'search result modality' or 'source modality' to refer specifically to the media type used for information presentation (e.g., video, website) on the SERP.

The significance of search result modality as a critical factor in web searching is evident in the evolving design of SERPs. In the past, organic search results did not feature multimodal elements, typically displayed in a list format on the SERP (e.g. Kammerer & Gerjets, 2014; Pan et al., 2007). These organic search results primarily comprised web pages indexed by search engines and displayed through plain text blocks. Since the internet landscape has transformed, increasingly featuring images and a growing number of videos (e.g., those uploaded on YouTube), search engines have also adapted by integrating more multimodal elements into SERPs. Consequently, universal search results have been increasingly incorporated into SERPs. Universal search results are specialized outcomes generated by vertical search engines that focus on specific types of information, such as news, images, maps, videos, or shopping (Arguello, 2017; Azzopardi et al., 2018). While in the past, universal results were only accessible via the tab design in search engines (e.g., clickable tabs like "Videos" or "Images"), these universal search results are now often integrated directly into the "All" – SERP (see Fig. 2 under the Google-Logo). Especially these universal search result snippets serve as previews of the actual resources modality and can strongly influence a user's initial selection. Therefore, understanding the role of modality in the search process is of significant importance.

This dissertation examines how the diversity of search result modalities (viewed as a resource factor) affects user selection behaviour across various types of knowledge (viewed as a contextual factor). The subsequent sections will introduce the general concept of contextual factors and provide a detailed categorization of the types of knowledge examined in this dissertation.

Figure 2

Original Search Result Page (SERP) with various snippets leading to different resources of different modalities.



1.4 Contextual factors

Lazonder and Rouet define contextual factors as “all relevant characteristics of the situation (place, time, equipment, people, and messages) that pre-exist the search activity” (2008, p. 756). They provide concrete examples, including the problem statement and the activities' conditions (e.g., time constraints, individual vs. tutored setting). Further, Lewandowski and Kammerer (2021) also introduce the task type (e.g., exploratory, fact-finding, complex research, navigational) and potential instructions accompanying the web search (e.g., think-aloud) as contextual factors influencing web searches. Following the initial definition of contextual factors of Lazonder and Rouet (2008), this dissertation argues that the kind of knowledge needed to solve an information problem (or task) can also be seen as a contextual factor.

A common differentiation between knowledge is the categorisation into factual, conceptual and procedural knowledge dimensions (e.g. Anderson et al., 2014). While a task type often refers to reaching a cognitive process dimension (remember, understand, apply, analyse, evaluate, create), the knowledge dimension can be seen as the components of information needed to reach this point. Since the task type and the kind of knowledge needed are predefined to the search activity, the type of knowledge can be seen as a contextual factor not influenced by the search.

Within the field of web search, other than the taxonomy of cognitive process dimension (e.g., Jansen et al., 2009; Wu et al., 2012), the differentiation of knowledge dimensions has rarely been used to investigate the search process and search behaviour. One of the exceptions is the work by Eickhoff et al. (2014), which used the differentiation into the conceptual and procedural knowledge dimensions to distinguish between search tasks. They found that within procedural search sessions, the average time spent increases towards the end compared to other search sessions. Beyond that, a clear differentiation in the cue words used for search sessions with either procedural (e.g. ‘how to’) or conceptual (‘what/ who’) knowledge intent could be observed.

The work of Urgo and colleagues (2019, 2020) offers a distinct view of the impact of a learning task's knowledge dimension on learners' search behaviours. Building upon Bloom's taxonomy for learning, teaching and assessing (Anderson et al., 2014), they highlight the importance of distinguishing between the 'knowledge dimensions' and the 'cognitive process dimensions' of a task in the context of search as learning scenarios. In their conceptual paper, Urgo et al. (2019) argue for a more nuanced consideration of these dimensions to enhance our understanding of how they influence search strategies and learning outcomes in online environments.

Following their argumentation, Urgo and colleagues (2020) further investigated the differences in search tasks classified into knowledge dimensions (factual, conceptual, and procedural). As expected, learners identified a stronger need for facts in factual tasks, a greater need for concepts in conceptual tasks, and a higher need for procedures in procedural knowledge tasks. The levels of cognitive activity were perceived as different between task types. Procedural knowledge tasks were associated with more 'applying,' 'evaluating,' and 'creating,' whereas conceptual knowledge tasks were perceived to involve more 'understanding' and 'analyzing' activities. Furthermore, procedural knowledge tasks were perceived as less complex than conceptual knowledge tasks. Likewise, when looking at the specific search behaviour, more queries were entered for conceptual tasks than procedural tasks, and it took longer to complete the former tasks.

As the work introduced before shows, the influence of knowledge dimensions on a web search is detectable but has not yet been sufficiently investigated in a differentiated manner. This dissertation will further elaborate on the definition of knowledge dimensions and, later on, knowledge types, which were designed to incorporate the degree of spatiotemporal relations and changes and their influence on the selection behaviour of modalities during web search as a novelty to existing research. Therefore, in the following section, we will introduce the knowledge types used (e.g. van Genuchten et al., 2012) and how they were derived from knowledge dimensions (Anderson et al., 2014) and further redefined.

1.5 Differentiation of knowledge dimensions

As outlined before, only recently, the field of web search has also focused on investigating in depth if and how different classifications of knowledge as a contextual factor influence the search process and outcome (Eickhoff et al., 2014; Urgo et al., 2019; Urgo & Arguello, 2022). Generally, there are plenty of categorisations and constructs of knowledge, especially within research investigating learning (for a list see

Alexander et al., 1991). Anderson and colleagues (2014) have refined the foundational taxonomy of educational objectives initially developed by Bloom and colleagues (1956). This framework differentiates knowledge dimensions and cognitive processes, which play an essential role in learning. It differentiates knowledge of tasks into the following dimensions: factual, conceptual, procedural, and metacognitive.

1.5.1 Factual knowledge

As the most fundamental dimension identified by Anderson and colleagues, factual knowledge comprises essential elements such as terminology and specific details crucial for problem-solving within a given topic (Anderson et al., 2014). In the context of web search, the pure need for factual information leads mostly to searching for single bits of information like, for example, 'What is the name of the king of Great Britain?' or a specific information detail like 'How old is he?'. Marchionini (2006) notes that such searches for factual knowledge typically result in straightforward look-up searches or simple question answering. Search engines often respond with discrete and well-structured information for this search inquiry. Through the simple nature of look-up searches, the knowledge dimension of factual knowledge plays no role in this dissertation. Similarly, the dissertation does not explore the metacognitive knowledge dimension, broadly covering understanding and regulating cognitive processes. In the following, the two main knowledge dimensions fundamental to this dissertation will be further elaborated, which can be differentiated by how they are queried (Ryle, 2009).

1.5.2 Conceptual knowledge

Requesting information by asking "what" or "that" often leads to pieces of factual knowledge. These pieces can be considered part of conceptual knowledge when integrated into more complex constructs, such as classifications, principles, or theories. Thereby, conceptual knowledge includes information on '[…] categories and classifications and relationships between and among them […]' and '[…] includes schemas, mental models, or implicit or explicit theories […]' (Anderson et al., 2014, p. 48). This definition corresponds with other research perspectives on conceptual knowledge (e.g. Alexander et al., 1991; de Jong & Ferguson-Hessler, 1996). De Jong and Ferguson-Hessel (1996) describe conceptual knowledge as surpassing simple factual understanding within a domain. It encompasses a more profound perception of the underlying concepts and principles essential for solving questions within that domain. In web search contexts, conceptual knowledge is viewed as more intricate and layered than factual knowledge, which fosters more advanced search behaviours, such as exploratory searches. Marchionini (2006) summarises under the term of exploratory search, all activities needed to investigate and learn about a topic while performing multiple activities like comparing, interpreting or analysing found information. In general, exploratory search tasks are more open-ended and need more query iterations than lookup searches (Soufan et al., 2022).

1.5.3 Procedural knowledge

The question of 'how to do something' leads to acquiring procedural knowledge (McCormick, 1997). This knowledge includes insights on how and when to employ specific skills, techniques, methods, or procedures relevant to a particular subject (e.g., Anderson et al., 2014; Corbett & Anderson, 1994). As a result, procedural knowledge 'helps the problem solver make transitions from one problem state to another' (de Jong & Ferguson-Hessler, 1996, p. 107). Similar to conceptual knowledge, searching for procedural information usually involves collecting multiple pieces of information rather than just a single fact that could be quickly found through a basic look-up search. In this dissertation, particularly in Experiment 2, conceptual and procedural knowledge dimensions were employed as opening elements to examine how these dimensions, as contextual factors, influence a learner's choice in selecting specific search results with varying modalities.

1.6 Spatiotemporal relations and changes

However, moving beyond the traditional distinction between conceptual and procedural knowledge, these two dimensions were further divided into knowledge types based on their extent of spatiotemporal changes. The concept of spatiotemporal relations and changes will first introduce the foundation for this classification. Building on this foundation, the subcategories of knowledge types, distinguished by their spatiotemporal characteristics, will be thoroughly detailed in the following section.

As early as during the preceding (and here not included) master thesis (Pardi et al., 2019), the thought arose that beyond the differentiation of the knowledge dimension, a further factor within the dimension could influence the preference for or against a specific search result modality. This master thesis investigated the search and justification behaviour of learners searching for procedural knowledge. It was found that while searching for information about the procedural task of ‘how to tie a figure eight note’, videos were preferred, while websites were preferred for the procedural task of ‘learn how to perform a while-loop in Python’. Based on this finding, further thoughts of differentiating the knowledge dimensions were discussed for this dissertation, potentially occurring in the same knowledge dimension (conceptual/procedural) but leading to different preferences for specific modalities. As a result, the concept of spatial relations, especially spatiotemporal changes, was potentially suitable for further differentiation.

It is important to note that a content-oriented approach drives the following differentiation regarding the degree of spatiotemporal relations and changes. This approach considers how many of these relations and changes can be represented when dealing with the type of knowledge. In this sense, it is an estimation of external visualizations. External visualizations (Knauff, 2023), such as images, graphics, and diagrams, serve as aids to resolve problems or interferences. However, it is essential to recognize that this content-driven approach does not directly consider how individuals address specific types of knowledge and questions. This would lead to the question of internal visualizations, which are mental, picture-like images individuals use as forms of mental representations for reasoning about concepts (Knauff, 2023).

1.6.1 Spatiotemporal relations

Throughout the day, we encounter numerous instances of information about spatial relations. For instance, when we ask a colleague about the location of the nearest post box, they might respond that it is situated on the same street as our favourite Asian restaurant but about one minute down the street in the direction of the institute, on the opposite side of the street. This example shows different information about spatial relations between different entities. Tversky (2005a, p. 2) argues that information about spatial relation is ‘typically qualitative, approximate, categorical or topological rather than metric or analogue’. The position of the postbox, and thereby the spatial relations beside it, has been described here by the colleague through text. However, it could also be illustrated through, for example, an image, an animation, or a map as a visual representation using arrows, lines, or information between distances. The resulting visuospatial representation would ‘capture visuospatial properties of the world’ (Tversky, 2005b, p. 211). Beyond that, static visuospatial properties of objects, such as shape, texture, colour, or reference frames like the distance or direction between objects, can be captured in visual representations (e.g., Tversky, 2005b). Thereby, it does not depend if the described object is a natural entity of the world like a post box or a concept representation, like a graph comparing the GDP growth of two countries (see Tversky, 2005a, p. 19). Nevertheless, spatial representations remain static since they show states and do not evolve, unlike spatiotemporal changes.

1.6.2 Spatiotemporal changes

Beyond the pure information about static spatial relations and visuospatial properties, spatiotemporal changes play a role in classifying differences with the same knowledge dimension. Spatiotemporal changes describe visual perceivable or depictable changes in entities' shape, size, or changes in spatial relations between entities like location, direction, or speed (Tversky, 2005b). An example of depictable spatiotemporal changes is how the shape of clouds transforms during a thunderstorm (change in height and development into an anvil cloud). The fact that spatiotemporal changes can be especially important within the context of learning has been shown by the meta-analysis of Ploetzner et al. (2020). Their work found that learning with animations was significantly more successful than learning with static images when spatiotemporal changes were essential to the task and displayed within the animation (Ploetzner et al., 2020). Considering this, we investigated the possibility of distinguishing the degree of spatiotemporal changes within knowledge types.

The following section will introduce different knowledge types as further sub-classifications of the procedural and conceptual knowledge dimensions. The classification of knowledge types has also been partly used in other research (e.g. van Genuchten et al., 2012) but not in the context of web search. Beyond that, the degree of spatiotemporal changes within knowledge types was generally not considered in previous works. Therefore, in the following, we will elaborate on the degree of spatiotemporal changes within the knowledge types.

1.7 Differentiation of knowledge types

1.7.1 Sensorimotor procedural knowledge

The first knowledge type introduced here is sensorimotor procedural (SP) knowledge. It comprises information for a procedural task involving motoric movements (e.g.

Bétrancourt & Benetos, 2018). The procedural character is evident by transmitting information about specific and sequential steps. The sensorimotor procedural knowledge type defined here aligns with the definition of procedural motor tasks by Garland and Sanchez (2013) or procedural-motor tasks by Höffler and Leutner (2007). An example of a task related to sensorimotor procedural knowledge can be seen in the effort to learn how to tie a specific nautical knot (Schwan & Riempp, 2004) or how to bandage a hand (Michas & Berry, 2000). Within tasks related to SP knowledge, all actions can be observed in the actual world and lead to spatiotemporal changes in objects and their relations. As a result, the degree of spatiotemporal changes within SP knowledge can be defined as high. Therefore, the possibility of representing steps and actions through visual representations of the concrete event through abstract (e.g., drawings) or concrete (e.g., images, videos) visualisations is possible.

1.7.2 Cognitive procedural knowledge

Tasks with a core of cognitive procedural (CP) knowledge have in common that they comprise information needed to conduct a procedural task requiring pure cognitive actions to solve the problem at hand. The manifestation of CP knowledge comprises knowledge about non-direct observable processes and steps that cannot be performed as visible actions. Examples of applying cognitive procedural knowledge would be solving a mathematical equation (Carlson & Lundy, 1992) or learning how to perform a logic operation within a programming language (e.g., while -loop). Within these examples, it is possible to externalise sub-steps, like a part of a calculation, visually. However, this remains an abstract visualization of results rather than the actual execution.

Consequently, while results and steps within CP knowledge can be represented visually, CP knowledge does not lead to immediate spatiotemporal changes that can be depicted visually. For example, altering a number in an equation represents a change to an object, not a spatiotemporal or relational change. Therefore, the extent of visuospatial and spatiotemporal changes in CP tasks can be considered low, particularly when compared to SP tasks.

1.7.3 Causal conceptual knowledge

Tasks with a core of causal conceptual knowledge (CC) have in common that they comprise conceptual information about cause-and-effect chains between and within different elements (van Genuchten et al., 2012). Thereby, different concepts can directly interact, resulting in new overarching constructs. For example, the interaction between the formation of clouds, the air and particle flow within clouds, and the phenomenon of lightning can be summed up with the concept of thunderstorms. This example has been used in several multimedia studies as a causal learning task (Moreno & Valdez, 2005; Mayer & Moreno, 1998). Within causal concepts, it is possible to depict, due to the involvement of multiple elements and their causalities, visuospatial properties (e.g., shape/colour of a cloud), spatiotemporal relations (e.g., the distance between cloud and ground), and spatiotemporal changes (e.g., growth and change of shape). Hence, the degree of spatiotemporal changes within CC tasks can be defined as high.

1.7.4 Relational conceptual knowledge

Tasks with a core of relational conceptual knowledge (RC) have in common that they comprise conceptual information about relations between and within different elements and are close to the definition of conceptual task by van Genuchten et al. (2012), the definition of relational categories by Gentner (2005), or what Anderson et al. (2001) described as knowledge of classifications and categories. Unlike factual knowledge, relation conceptual knowledge includes, beyond the pure facts, the knowledge about connecting links between and among different concept elements (e.g. Anderson et al., 2014). Examples of tasks linked to relational conceptual knowledge would be to explain ‘how hares and rabbits are related’ or ‘describe the differences between weather and climate’. Within relational concepts, it is possible to depict, due to the involvement of multiple elements and their relations, visuospatial properties (e.g. shape/colour) and compare them, but no direct spatiotemporal changes are observable. Hence, the degree of spatiotemporal changes within RC tasks can be defined as low, especially compared to CC tasks.

1.8 Modality and knowledge type within the initial stages of IPS-I model

In the following, the general process of finding information will be elaborated, and potential points where the resource factor modality and the contextual factor of knowledge type potentially influence the web search at the initial stages will be discussed.

In the first step, searchers must recognise and accept the need for additional information to start taking action to fulfil the need (Marchionini & White, 2007). Therefore, the sub-steps of the first steps described in the IPS-I are to read the task, formulate questions, activate prior knowledge, clarify task requirements and determine the needed info. This dissertation argues that at this first step of the process, the contextual factor of the aspects of knowledge type potentially plays a role and influences the steps. When learners match the need for information with available prior knowledge, they may assess what information they need to fulfil the task. For example, when learning about the formation of thunderstorms and lightning, learners could reflect on their mental models and find a basic understanding of factual knowledge related to the phenomena (e.g., the height and shape of clouds, the difference in temperatures). They then realise they know factual parts but do not know how these causally influence each other. Therefore, when activating prior knowledge and determining the needed info, learners may also have a conscious or subconscious understanding of the type of knowledge they seek.

Another example of procedural knowledge would be when a learner is assigned to learn how to perform the recovery position on an unconscious person. The learner may already be familiar with the final position but may not know the correct sequence of steps to achieve it. In this case, the individual would seek step-by-step instructions, targeting procedural knowledge. Conversely, the learner might know the sequence of steps but lack specific information, such as why the proper alignment of the head—is either inclined or overstretched. In this case, the learner may seek factual knowledge possibly presented through images or videos. After the learner has mastered both the correct sequence and final position, they might become interested in how the position of the overstretched nack is related to the risk of choking. This interest triggers the search for conceptual knowledge. These examples underscore the need for a more nuanced consideration of the type of knowledge sought during the initial steps of the model.

The second step is to search for information and, therefore, conduct sub-steps like selecting the search strategy, specifying search terms and judging the found search results. The first sub-step, selecting a search strategy, is often related to the decision to use a search engine or directly navigate through a URL to a specific domain (c.f. Kuiper et al., 2008). When a search engine is used as a ‘strategy’, search terms are formulated, and the results presented on a SERP must be investigated and then judged regarding suitability. Within this dissertation, the thought should be emphasised that a more complex approach to defining search strategies is needed beyond the decision to use or not to use a search engine since the judgement and presentation of search results have become more complex. While in the past, search engines dominantly offered textual results in a list structure (Haas & Unkel, 2017; Kammerer & Gerjets, 2014; Pan et al., 2007), nowadays, multimodal search results are included in varying SERP designs (see Figure 1), which increases the complexity of search results and SERPs. Beyond classic search results, featured snippets (Bink et al., 2022), enriched search results (Marcos et al., 2015), and universal snippets leading to images or videos (Azzopardi et al., 2018) are included (see. Figure 2). These developments show that learners potentially face search results of different modalities (e.g. video, image, website).

Nevertheless, most web search models do not adequately reflect and address these circumstances. Furthermore, being confronted with various search results, modalities can potentially influence the different subprocesses within these models. For instance, users may select a specific search strategy, such as exclusively opting for video results, or they might evaluate the cost and utility of different types of results, preferring text for its faster searchability. This dissertation investigates the influence and interaction between the type of knowledge tied to a specific task and the modality associated with search results. Utilizing the framework of the IPS-I model as a guide, the research primarily concentrates on the first two phases of the process. Initially, an exploratory examination was conducted to study the general distribution of different modalities in an unrestricted web search (Experiment 1). Subsequently, controlled experiments (Experiments 2 and 3) were carried out to assess whether specific types of knowledge lead to preferences for certain modalities, even in the absence of actual search results.

The ultimate goal is to establish whether a direct link exists between the task at hand and the preferred modality. Finally, the findings of these controlled studies were aligned with actual search result snippets, and their impact on selection behaviour was analyzed (Experiment 4).

2 Summary and overview of studies

Six studies were conducted to analyze web search behaviour and the influence of knowledge type and modality, involving 736 participants. This work has led to the specific four experiments introduced in the following, leading to three publications. Beyond that, Experiment 1 (Pardi et al., 2022) enabled further investigations into aspects such as learners' metacognitive judgments (von Hoyer et al., 2022), the predictability of knowledge gains during web searches (Otto et al., 2021), and the creation of an accessible and comprehensive eye-tracking search-as-learning dataset (Otto et al., 2022).

2.1 Experiment 1

The first experiment (Pardi et al., 2022) unfolded in two stages. During the first stage, participants completed an online pre-test to evaluate their prior knowledge of the subject. The second stage brought 130 students into a laboratory setting to learn about the formation of thunderstorms and lightning. This topic was chosen as it has been widely used in various multimedia research studies (e.g. Moreno & Mayer, 1999; Schmidt-Weigand & Scheiter, 2011). Participants were informed that they could use the provided browser (Google) to access various resources, including websites, videos, or images, to learn about the topic at their own pace within a maximum time limit of 30 minutes. Participants were advised to stop at any point if they felt they had acquired enough knowledge of the subject. Subsequently, all search activities and selection decisions were accurately monitored through eye-tracking, screen recording and data logging. In addition, all web pages visited were simultaneously crawled using an unnoticeable HTML plugin. The reconstruction of the visited webpages was possible by storing the HTML files, allowing for detailed analysis of the viewed HTML areas, which were categorized into text, image, or video segments. By leveraging the ability to reconstruct the HTML files and aligning them with eye-tracking data through the reading protocol developed by Hienert and colleagues (2019), the study was able to calculate the distribution of fixated modalities, providing deeper insights into how learners use different modalities to learn during a web search about a causal conceptual task.

2.2 Experiment 2

While Experiment 1 explored the participants' free search behaviour while learning about a causal conceptual task in an exploratory manner, the second study served as an initial step to investigate how both the contextual factor of knowledge type and the resource factor of modality influence the initial stage of the search process. Experiment 2 (published in Pardi et al., 2023) was carried out in two phases and involved 61 participants. In the first phase, participants were asked to complete an online survey, where they were required to self-assess their prior knowledge concerning twenty hypothetical search tasks. The hypothetical search tasks (5 for each knowledge type) were constructed based on the differentiation of knowledge dimensions and types introduced earlier. In the second phase, participants were invited to the lab, where they were provided with a general introduction to the search scenarios. In this context, participants were instructed to imagine that they had to learn enough about each presented task to solve or perform it, using the Google search engine to find relevant information. The presentation of the search tasks was standardized by first displaying the task topic. Participants were then asked to a) formulate the search query they would use and b) rank their preferred modality (pictures, texts without pictures, text with pictures, videos) of information for learning about the task. The main point of Experiment 2 was to investigate how different knowledge types and the option to select various modalities interact.

2.3 Experiment 3

Experiment 3 (published in Pardi et al., 2023) involved 69 participants and investigated in greater detail the selection of search result modalities depending on knowledge types. This study built on theoretical considerations from Experiment 2, yet it introduced methodological changes. Firstly, the number of questions for each knowledge type was reduced, presenting only four tasks per category to participants. Secondly, the modalities and the methods for indicating their usage likelihood were redefined. Following a clear trend identified in Experiment 2, favouring multimodal options (combining text, images, and videos), single-modal choices (text-only, picture-only) were excluded. Also, the options were reframed to align more closely with typical search settings, rebranding 'videos' to 'online videos' and 'text with pictures' to 'websites with text and pictures.' Regarding the operationalization of the dependent variable 'likelihood of usage,' the methodology was shifted from ranking preferences to using a Likert scale (ranging from 1='not at all' to 7='very likely') to assess the likelihood of using each modality for learning tasks. Additionally, this experiment examined in more depth the division of knowledge dimensions concerning the factor of spatiotemporal relations and changes.

2.4 Experiment 4

Experiment 4 (published in Pardi et al., 2024) was an online study involving 225 participants. Its primary aim was to replicate the earlier findings on the impact of knowledge types, particularly the degree of spatiotemporal changes, on the likelihood of selecting specific modalities in a realistic search environment. The methodology was refined to assess participants' probability of choosing particular search result modalities. For the first time, participants were presented with realistic search result snippets for sixteen tasks derived from Experiment 3 across two modalities: websites featuring text and images and online videos. Two types of snippets were constructed: (a) website snippets, which included the URL, title, and abstract, and (b) video snippets, which featured the title, abstract, uploader information, and thumbnail. The HTML layout of these snippets was designed to mirror that of Google's search engine results pages. Also, the study manipulated source reputation as a resource factor, identifying the sources in search result snippets as either high or low reputation. Additionally, the presence or absence of images in the search results was controlled as a between-subjects factor. This control was designed to ensure that the expectation of the search result modality (video or website) influenced the likelihood of selection rather than the visual presence of an image within the search results.

3 Objectives and expected outcomes of the current dissertation

The overarching hypothesis was that the knowledge type associated with a task and its inherent characteristics can predict the likelihood of selecting a particular search result modality during a web search. This idea was first suggested in my master's thesis (Pardi et al., 2019), where an exploration into the justification behaviour of searchers during staged web searches for procedural knowledge revealed that the modality of search results, often mentioned alongside the procedural aspect of the task, was frequently cited as a basis for selection. Further supporting this, various studies have demonstrated that contextual factors, such as the underlying characteristics of a task's knowledge type, significantly influence web search behaviour (Eickhoff et al., 2014; Hienert et al., 2018; C. Smith et al., 2022; Urgo et al., 2019). Despite these findings, there remains a gap in the literature concerning the impact of different knowledge types on the selection process of search results.

Therefore, based on previous literature (Anderson et al., 2014; Eickhoff et al., 2014), conceptual and procedural knowledge dimensions were selected as a starting point and further categorized into knowledge types (van Genuchten et al., 2012), taking into consideration the degree of spatiotemporal changes. This work's initial thesis assumed that search tasks with a procedural knowledge core would lean towards predominantly visual modalities (such as video and picture). Although a difference within the type of procedural knowledge was already found in the previous master's thesis, this assumption was fundamentally re-examined. Therefore, it was reviewed again, incorporating the additional type of conceptual knowledge. In contrast, the thesis was that search tasks related to conceptual knowledge would lead to a preference for primarily textual modalities (such as pure text and text with pictures).

However, this working thesis was modified during the dissertation. The results indicated, in line with the conclusion of the master thesis, that the knowledge dimension alone could not explain the observed patterns of modality preference. Therefore, the thesis and expectations regarding the influence of the interaction between modality and knowledge type were updated by considering the degree of expected spatiotemporal changes within a knowledge dimension as a factor. This approach reflects the idea that it is not solely the knowledge dimension but also the degree of visuospatial changes within the knowledge type that influences the effectiveness of learning material. This idea that visuospatial changes play a role is derived from meta-analyses in the field of learning with media, particularly from the area of learning with the help of moving images such as animations (Ploetzner et al., 2020).

Based on this, it was hypothesized that tasks related to a type of knowledge with a high degree of visuospatial changes (sensorimotor procedural, causal conceptual) are more likely to benefit from the visualization of information and, therefore, subconsciously trigger the selection of search results related to dynamic representations of changes (e.g., video). In contrast, types of knowledge that do not involve visible visuospatial changes (cognitive procedural, relational conceptual) are more likely to lead to the choice of static modalities (e.g., text).

4 Summary of results

This section will describe the overarching findings of the present doctoral research. Furthermore, additional insights not included in the published manuscripts will be discussed. First, the exploratory Experiment 1 results and additional information about the first selection decision will be reported.

4.1 Modality selection and usage during a causal conceptual task

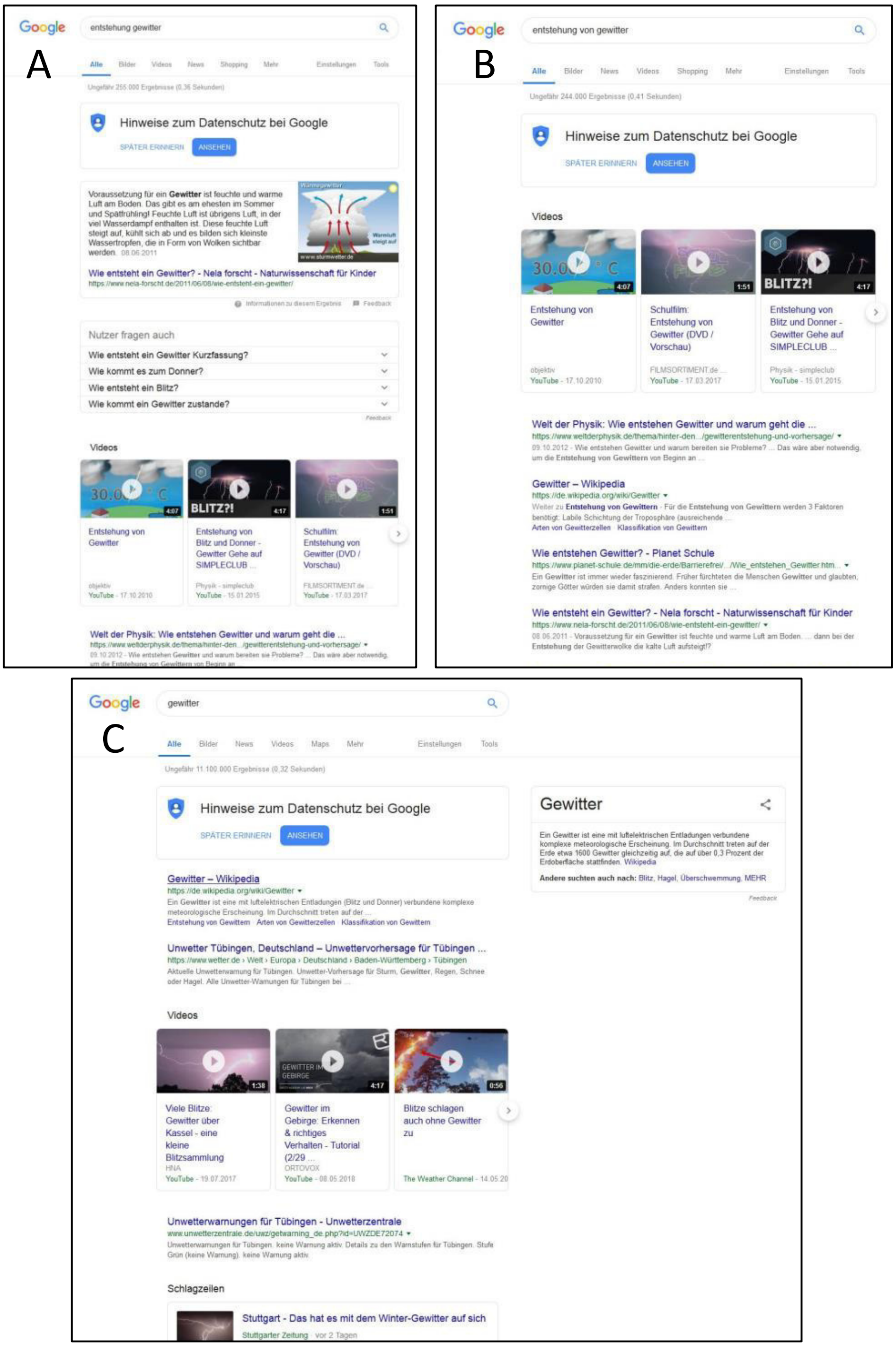
As found in Experiment 1 (N= 108), learners spent more of their total learning time on fixating websites (M = 54.39%, SD = 24.81) compared to video resources (M = 38.99%, SD = 25.54) when searching and learning about a causal conceptual task. With regards to the first selection decision of learners on the SERP, additional analyses show that the majority of 53.7% chose websites as the first search result type, followed by video (33.3%), featured snippet (8.3%), image (2.8%) and question search results (1.9%).

Interestingly, 36 out of 108 participants chose video as their first search method. Notably, 15 of these 36 video-focused searchers went directly to YouTube or selected the video search results tab before entering a search query or viewing any other results. Also, 3 participants directly navigated to the Google image tab, not using the SERP to enter a search query. This finding indicates, referenced to models describing the procedure of web search (e.g. IPS-I, Walraven et al., 2008), that nearly half of the video users and three image users had already decided within the sub step of *selecting a search strategy* that depictions would be their modality of choice without being influenced by any other resource factor. For the other 16 participants who first selected a video search result, it is unclear whether their choice was influenced by resource factors, such as the appearance of the search result or the type of information conveyed, since their decision to select a video was made after they saw a SERP.

Since 15 of the 108 participants directly selected a video option and three immediately chose the image search results page (SERP), only 90 participants were confronted with a traditional SERP for their first search interaction. Interestingly, in 50 of these 90 cases, a featured snippet was displayed as a search result, combining an image with a text excerpt (see Figure 3A, top). In 84 of the 90 cases, the SERP included at least one video result or a video carousel, which highlights how SERPs nowadays heavily incorporate multimodal resources.

Figure 3

Various Search Engine Results Pages (SERPs) encountered during Experiment 1 showed different search result modalities, including website, video, featured, and image search results.



4.2 Interaction of knowledge type and modality within selection scenarios

A consistent interaction was found in all controlled studies (Experiment 2-4) investigating the initial modality selection. The knowledge type as a contextual factor interacts with the modality of a task, representing the resource factor.

As introduced earlier, based on the influence of literature (see section 1.6), the two knowledge dimensions were further differentiated into knowledge types regarding spatiotemporal changes. Within each dimension, two knowledge types, either high or low (see section 1.7), were defined. Therefore, knowledge types of sensorimotor procedural (SP) and causal conceptual (CC) included a high degree of spatiotemporal changes relevant to learning. In contrast, relational conceptual (RC) and cognitive procedural (CP) knowledge types were categorized as sharing a low degree of spatiotemporal changes observable and relevant for learning.

4.2.1 Knowledge types with a high degree of spatiotemporal changes

The following picture emerged across Experiments 2-4 for the concrete knowledge types with a high degree of spatiotemporal changes*:*

For sensorimotor procedural (SP) knowledge tasks, a stable preference for video search results can be obtained across Experiments 2-4. While in Experiment 2, the preference was measured through building a rank (1 = 'first choice',4 = 'last choice'), the video (M = 1.38, SD = 0.56) option was significantly (p < .001) higher ranked than the text with pictures (M = 2.13, SD = 0.44). In Experiments 3 and 4, the approach was changed from ranking to rating the likelihood of selection, using a scale from 1 ('not at all') to 7 ('very much'). In Experiment 3, videos showed a significantly (p < .001) higher preference (M = 6.53, SD = 0.64) compared to websites (M = 4.19, SD = 1.16). Also, in Experiment 4, where actual search results were presented for the first time, video search results (M = 6.02, SD = 1.04) were preferred (p <.001) to website search results (M = 4.86, SD = 1.43).

An ambiguous pattern was found for causal conceptual (CC) knowledge. While in Experiments 2 (video: M = 1.80, SD = 0.75, text with pictures: M = 1.70, SD = 0.53) and 3 (video: M = 5.79, SD = 0.81, text with pictures: M = 5.32, SD = 0.90), no significant differences between preferences for either a video or text with pictures/websites were found, in Experiment 4, the preference for videos (*M* = 5.65, *SD* = 1.18) exceeded the preference for websites (*M* = 5.10, *SD* = 1.35) significantly ($p < .001$).

4.2.2 Knowledge types with a low degree of spatiotemporal changes

For the relational conceptual (RC) knowledge type, in Experiment 2, a significant (p <.001) advantage for text with Pictures (*M* = 1.65, *SD* = 0.50) over videos (*M* = 2.40, *SD* = 0.72) was found, which was also confirmed in Experiment 3, where websites (*M* = 5.89, *SD* = 0.80) were more likely ($p < .001$) to be selected as preferred search result modality compared to videos (*M* = 4.76, *SD* = 1.21). This advantage for text with pictures/websites vanished in Experiment 4, where no significant difference in the likelihood of selection could be between the video (*M* = 5.28, *SD* = 1.24) or website (*M* = 5.34, *SD* = 1.28) modality.

Within the tasks related to the cognitive procedural (CP) in Experiments 2 and 3, again, a significant advantage for texts with pictures and websites over videos was found. In Experiment 2, the Text with pictures modality ranked highest as the first choice with M = 1.58 (*SD* = 0.47), while videos were ranked second choice (M = 2.36, *SD* = 0.75). Again, in Experiment 3, websites (*M* = 5.94, *SD* = 0.94) were significantly ($p < .001$) more preferred than videos (*M* = 4.60, *SD* = 1.21). As well as for the relational conceptual knowledge, this preference for text with pictures/website modality disappeared when using a realistic search scenario with actual search results in Experiment 4. A parity was found between websites (*M* = 5.15, *SD* = 1.45) and videos (*M* = 5.28, *SD* = 1.24).

Table 1

Mean preference rank (with SD) for the four modalities as a function of knowledge type

Spatiotemporal Changes	Knowledge Type	Modality				
		Text with Pictures		Video		
Experiment 2		M	SD	M	SD	Statistic
high	Sensorimotor (SP)	2.13	0.44	1.38	0.56	**p < .001**
	Causal (CC)	1.70	0.53	1.80	0.75	p > .999
low	Cognitive (CP)	1.58	0.47	2.36	0.75	**p < .001**
	Relational (RC)	1.65	0.50	2.40	0.72	**p < .001**
		Websites		online video		
Experiment 3		M	SD	M	SD	Statistic
high	Sensorimotor (SP)	4.19	1.16	6.53	0.64	**t(172) = -12.80, p < .001**
	Causal (CC)	5.32	0.90	5.79	0.81	t(172) = -0.47, p = .299
low	Cognitive (CP)	5.94	0.94	4.60	1.39	**t(172) = 7.35, p < .001**
	Relational (RC)	5.89	0.80	4.76	1.21	**t(172) = 6.19, p < .001**
		Websites		online video		
Experiment 4		M	SD	M	SD	Statistic
high	Sensorimotor (SP)	4.86	1.43	6.02	1.04	***b* = 1.16 (95% CI, 0.89, 1.43), *t*(629) = 13.51, p < .001**
	Causal (CC)	5.10	1.35	5.65	1.18	***b* = 0.54 (95% CI, 0.27, 0.81), *t*(629) = 6.30, p < .001**
low	Cognitive (CP)	5.16	1.30	5.15	1.45	*b* = -0.00 (95% CI, -0.26, 0.26), t(629) = -0.082, p > .999
	Relational (RC)	5.28	1.24	5.34	1.28	*b* = 0.05 (95% CI, -0.21, 0.33), t(629) = 0.68, p > .999

5 Discussion

One of the central findings of this dissertation is that simple tasks categorised into knowledge dimensions (procedural or conceptual) are inadequate for fully understanding the differences in modality selection during the initial stages of web searches. It could be shown that tasks of knowledge types sharing the same background of knowledge dimension (procedural or conceptual) did not lead to a coherent selection pattern overall. For example, a task requiring knowledge about a cognitive procedure did lead to a preference for texts with pictures/websites as a modality, while in contrast, a task requiring knowledge about a sensorimotor procedure led to a preference for video as a modality. Although both knowledge types are classified as procedural knowledge, sharing the commonality of dealing with tasks that must follow exact sequences of steps, this similarity did not lead to a consistent preference for one modality. The same observation applies to the two knowledge types within the classification of the conceptual knowledge dimension. Tasks requiring knowledge about conceptual relations led to a preference for texts with pictures or websites, while tasks requiring knowledge about conceptual causalities led to an increased preference for video results. Therefore, based on these observations, the additional factor of spatiotemporal changes observable within different knowledge types seems essential to explain modality selection during a web search in depth.

Furthermore, it must be clarified that more research is needed to investigate additional potential factors influencing modality selection. The initial hypothetical search result selection investigation has been examined throughout the dissertation using different approaches and adaptations (e.g., including search results and images). These variations have led to changes in tendencies regarding modality preference. Therefore, approaching a more realistic setting and the influences that come with it must be further investigated.

5.1 Interaction of Knowledge Type and Modality

Concerning the interaction investigated between types of knowledge as a contextual factor and the modality of search results as a resource factor, all experiments found a significant interaction between these variables. The type of knowledge influenced the probability of selecting a specific modality of search results. This discovery — that learners exhibit an adaptive preference for specific modalities depending on the task context, at least for the first selection decision without further influences — offers valuable and novel insights into the processes of searching and learning via web search. Furthermore, the increasing importance of video resources for learning (see Feierabend et al., 2021; Huang & Archer, 2017; A. Smith et al., 2018) is reflected in the findings of this dissertation. The results indicate a manifest consideration of videos when searching for information online, particularly for knowledge types characterized by high spatiotemporal changes (SP/CC). Especially across all experimental conditions, videos appeared as the preferred modality for sensorimotor procedural tasks (SP).

For causal conceptual tasks (CC), videos and websites were equally favoured in the hypothetical scenarios of Experiments 2-4. However, in the realistic search environment of Experiment 1, which allowed for an open web search, this preference shifted, revealing a preference for websites and textual content. This observation suggests that the nature of an open search environment influences the relationship between knowledge type and modality preference, potentially due to uncontrolled contextual and resource factors. It may be that, in the sense of a contextual factor, the mission of explaining a complex matter to someone else, coupled with a time restriction of 30 minutes, had a direct influence on which modality was chosen as a heuristic response to fulfil the task, rather than acting according to one’s own preferences. Therefore, it would be interesting to further investigate in detail the influence of additional contextual factors such as time, task goals, and access to information (e.g., via mobile or computer) on the structure of the search process. It would also be valuable to explore whether it is possible to identify searcher profiles that could be predicted based on information about the searcher in different contextual settings. Scaffolding could be more effectively tailored to assist learning by predicting searchers' approaches or heuristics. It would be interesting to investigate this in a free and long-term analysis of how web searches behave in the context of types of knowledge (e.g. D’Aquin et al., 2017).

An interesting pattern emerged regarding knowledge types characterized by low spatiotemporal variability (CP/RC) across Experiments 2-4. While websites were the preferred modality in Experiments 2 and 3, Experiment 4 demonstrated no disadvantage for videos, suggesting an equal preference for both websites and videos. Experiments 2 and 3 initially assessed modality preference textually and hypothetically without presenting actual search results. In Experiment 2, participants were introduced to generic modalities (text only, text with pictures, pictures alone, and videos) and their combinations. Experiment 3 featured options directly related to web searches (websites with text and images, online videos), while Experiment 4 provided participants with realistic search result snippets.

The move towards a realistic setting, showcasing actual search results, clearly favoured video results for cognitive procedural (CP) and relational conceptual (RC) knowledge types, demanding further investigation. One possible explanation is that the operationalization chosen for Experiment 4, including images in both website and video search results, had a more substantial impact than expected. Although combining images with textual elements is increasingly common, this presentation might have been unfamiliar to participants, leading to a preference for the more established video search result format. However, it should also be noted that the influence of images was inserted as a control hypothesis in Experiment 4. In this context, neither the main effect of including an image (p = .928) nor its interaction with resource modality (p = .061) reached statistical significance. This suggests that adding an image to a video or website search result did not significantly influence the likelihood of that search result being selected in this study. However, descriptively, when no image was included in the search results, the preference difference between video (M = 5.47) and website (M = 5.16) modalities was more negligible. In contrast, when an image was included in both modalities, the difference in preference became more pronounced, with video (M = 5.61) being preferred over websites (M = 5.04).

Nevertheless, compared to knowledge types with low spatiotemporal changes, the preference for videos remained stable across experiments for sensorimotor procedural (SP) and causal conceptual (CC) tasks, which can be summarized as knowledge types with a high proportion of spatiotemporal changes. This finding suggests that videos are already considered a viable option for knowledge types characterized by important spatiotemporal changes before encountering actual search results with pictures. This preference and the decision-making process regarding search result modality, in conjunction with knowledge type, should be thoroughly discussed and integrated into theoretical models.

5.2 The knowledge type influencing the search strategy selection

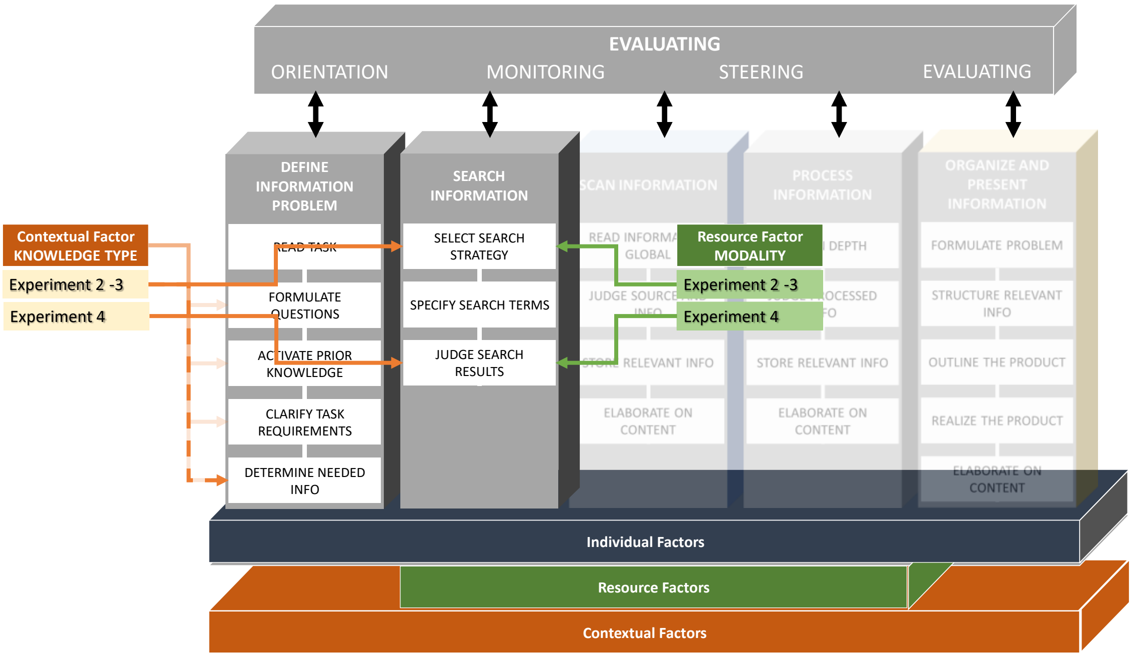
Research has demonstrated that contextual and resource factors can significantly influence general web search behaviour (e.g. Hienert et al., 2018; Lewandowski & Kammerer, 2021; C. Smith et al., 2022). However, there remains a gap in examining the impact of these factors on the single steps of the search process. A key finding of this dissertation is the influence of the contextual factor of knowledge type on the search process in the initial steps. Unlike previous studies, this research isolated this factor, examining it without the confounding effects of other variables such as the ranking of results on the search engine results page (e.g. Kammerer & Gerjets, 2014; Pan et al., 2007; Slechten et al., 2022; Unkel & Haas, 2017), the presence of credibility cues (Unkel & Haas, 2017), or images (Capra et al., 2013), which could otherwise affect the strategy selection process.

It could be argued that, in alignment with the IPS-I Model, within experiments 2-3 — where participants had the autonomy to select their preferred modality for solving tasks related to specific knowledge types — they engaged in the 'selecting a search strategy' step (see Figure 4), specifically selecting a modality as a strategic approach. However, this step in the IPS-I Model is traditionally interpreted as deciding on a broader strategy, such as using Google or directly accessing a specific website. This observation prompts a critical inquiry: if a searching strategy is not required in the experimental design, how should we classify the act of choosing a preferred resource modality depending on the knowledge type? Since a preference exists independently of additional resource information (e.g., SERP design, quality of search results), should this not be integrated into the model? Furthermore, could one argue that in the first pillar, 'define information problem,' the step of 'determine needed information' is already influenced by the contextual factor of knowledge type, thus predisposing users towards a modality preference (as indicated by dashed lines in Figure 4)? Experiments 2 and 3 demonstrated that this finding, the type of knowledge influences modality preference in the early stages of web search. Specifically, in the absence of visible search results in this initial stage, participants preferred video content when tasks involved high degrees of spatiotemporal changes (SP, CC) and text-based content for tasks with lower degrees of such changes (CP, RC).

This dissertation suggests refining web search models to better integrate the initial selection of search results and highlight contextual and resource factors' influence before displaying search outcomes. Traditional models like the IPS-I (Brand-Gruwel et al., 2005, 2009; Walraven et al., 2008) recognize individual factors but do not sufficiently represent the impact of contextual and resource factors on web searching. Exploring these factors within frameworks like the IPS-I, potentially utilizing classifications from Lazonder and Rouet (2008) and Lewandowski and Kammerer (2021), could enrich these models (see Figure 4). This discussion is to be understood as theoretical and, naturally, requires further empirical investigation. However, it is intended to serve as a spark for additional research. While individual factors of learners (the first foundation) are acknowledged across all stages of the web search process and integrated into models such as the IPS, the inclusion of contextual factors (the third foundation), like knowledge type or the search environment, remains underexplored. These factors likely influence the entire information search process from the start. Likewise, resource factors (the second foundation) are often overlooked despite their significant role during the searching, scanning, and processing stages. Adopting an approach similar to Rouet and Britt's MD-TRACE model (2012; 2011), which emphasizes the need for learners to access diverse informational artefacts for effective learning — not just texts but also images, data tables, and cartoons — could significantly benefit the understanding of resource utilization in learning.

Figure 4

Enriched IPS-I Model with consideration of Resource and Contextual Factors investigated in the Experiments of the Dissertation.



5.3 Limitations and Future Research

One limitation of this study is the generalizability of findings derived from hypothetical search scenarios to explore the interplay between modality selection and knowledge types. Although hypothetical scenarios were employed across all four knowledge types, actual modality selection was not measured in a fully open web environment; real interactions were observed only for the causal conceptual (CC) knowledge type in Experiment 1. The shift to a controlled hypothetical setting after Experiment 1 was designed to isolate the direct interaction between knowledge type and modality. This approach was essential to minimize the influence of external factors typically present in realistic settings, such as rank (Haas & Unkel, 2017; Kammerer & Gerjets, 2014; Pan et al., 2007), source (Kattenbeck & Elsweiler, 2019; Unkel & Haas, 2017), and the positioning of additional search results and keywords (Lo et al., 2014).

Another limitation of the studies and the general methodological approach is the unclear differentiation between the degrees of high and low spatiotemporal changes used to classify knowledge types. While it is clear how the distinction between spatiotemporal relations and changes arises according to Tversky (2005b, 2005a), no quantifiable measure was found or applied to clearly define, for instance, how much more visually conveyable content (e.g., spatiotemporal changes) distinguishes two tasks of the same knowledge dimension or even type. Theoretically, it could be attempted to evaluate directly comparable tasks (e.g. binding a complex knot vs. easy knot) of the same type, such as sensorimotor procedural tasks, to determine how the number of changes develops. This could help infer whether search behaviour changes based on a quantifiable number of changes.

Also, this research focused on spatiotemporal relationships and changes in external visualization (Knauff, 2023) and knowledge perspectives. However, it did not explore why (for example, through interviews) participants selected specific search results to solve the problems at hand. A closer examination might reveal what learners expect from the different modalities (e.g. faster access to information in terms of cost-benefit analysis) or how learners use external visualizations to enhance their understanding and influence their internal representations of concepts. It is important to emphasize that there is only a preference for or against visual representation discussed without delving into the old debate of visualizers versus verbalizers (Kirschner, 2017). In the conceptual derivation of the differentiation used in this study, individuals may process some edge cases differently. For example, Knauff showed that brain areas are activated even in cognitive processes that do not require visual input, which indicates the use of spatially organized mental models (Knauff et al., 2002). This suggests that even tasks with low spatiotemporal changes, such as understanding algorithms, might trigger different expectations for visual representations depending on the individual.

Future research could benefit from examining the dynamics between knowledge types in a controlled yet more realistic search environment. A potential starting point could be presenting multiple controlled websites and video search results on a simulated search engine results page (SERP), manipulating variables such as rank, credibility, and additional information to assess their impact on modality preference within specific knowledge contexts. Advancing towards a more realistic setting, replicating Experiment 1 with a broader array of tasks across all four knowledge types could provide deeper insights. This approach would enable comprehensive data collection through eye-tracking and log analysis, explaining search and learning behaviours in an open web context and their variations across different knowledge types. Given the documented influence of task complexity on measurable behaviours

(Eickhoff et al., 2014; Urgo et al., 2020), behavioural metrics such as fixation on text versus video content (Pardi et al., 2022) or actions related to browsing, mouse movement, and initial SERP interactions (Yu et al., 2018) could significantly vary between tasks of different knowledge types. Additionally, several studies (e.g. Hienert et al., 2018; Urgo et al., 2019) have characterized tasks based on their complexity, as defined in Bloom's Taxonomy of cognitive process dimensions (e.g., remember, understand, apply) (Anderson et al., 2014). Exploring the cognitive process dimension concerning knowledge types could yield further insights into the web search process.

Moreover, the limitations of individual factors must also be addressed. Primarily, university students were used as participants, and as the literature suggests, factors such as age (Bilal & Gwizdka, 2016), prior knowledge (Cole et al., 2011; Sanchiz et al., 2017), and gender (Singer et al., 2012) can influence the search and selection process. Although self-assessed prior knowledge was measured in all studies, we did not control for variables like computer skills or self-regulating abilities. Future studies should consider these individual factors and their potential interactions with contextual and resource factors.

5.4 Conclusion and Outlook

This dissertation demonstrates that the contextual factor, precisely the knowledge type of a task, significantly influences learners' preferences for selecting search results of a particular modality during the initial stages of web search. While no consistent preference for video or websites emerged across different tasks, the three experiments (each using different operationalizations) showed that the characteristics of the knowledge type noticeably affect modality preferences. This insight, which illustrates the adaptation of preference concerning the knowledge type, could significantly enrich the discourse on learners' selection of search strategies within theoretical frameworks (Kiili et al., 2018; Rouet & Britt, 2011; Walraven et al., 2008). Additionally, the findings highlight that the selection decision is beyond the standard classification into procedural and conceptual knowledge dimensions (Anderson et al., 2014), further influenced by the degree of spatiotemporal changes within a task (Ploetzner et al., 2020; Tversky, 2005b). This suggests that expected spatiotemporal changes could be a primary consideration in analyses of learners' search behaviours when predicting the preferred search results modality. Critically, further research is essential, especially since preferences for modalities in tasks with minimal spatiotemporal changes showed variability as the studies moved towards a more realistic setting. Despite these variations, the findings of this dissertation aim to guide future explorations into learners' online search and selection practices, posing new questions and suggesting avenues for further inquiry.

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7 Appendices

Appendix A: Manuscript 1(Experiment 1)

Appendix B: Manuscript 2 (Experiments 2 and 3)

Appendix C: Manuscript 3 (Experiment 4)

Appendix A: Manuscript 1 (Experiment 1)
The following is the published article under:

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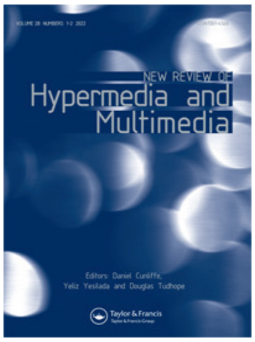

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Examining the use of text and video resources during web-search based learning—a new methodological approach

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ABSTRACT

The present paper introduces a new methodological approach to capture and analyse the processing and use of text, images, and video content during web-search based learning on the free web. We asked 108 university students to search the web to learn about a natural science topic while recording their eye movements and navigation behaviour. Then, we used the 'reading protocol' software to automatically map participants' fixations to text, images, and video content that they had fixated upon on any information resource retrieved. Moreover, we retraced words from participants' post-search essays to words encountered in fixated text or in transcripts of viewed videos, in order to calculate the degree of overlap. Our results showed that the participants directed their attention significantly longer to text than to video or image resources. Nevertheless, multiple video resources were visited by the great majority of students, underlining the importance of videos in web-search based learning. Regarding the origin of learned concepts, more words included in the post-search essay could be retraced to fixated text than to words contained in transcripts of viewed videos. To conclude, we were able to retrace large parts of students' acquired knowledge to retrieved information resources with our approach.

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1. Introduction

The web has become a major knowledge resource, and thus, is also regularly used for learning purposes (e.g. Kammerer et al., 2018; Vakkari, 2016), with learning by searching the web being considered as "an active and critical process of knowledge building" (Mason et al., 2010, p. 629). To find

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information online, individuals typically use search engines, such as Google, which has become a natural feature of the web (Hillis et al., 2012), providing easy access to vast amounts of information resources on almost any topic. Moreover, the web in general, and search engines in particular, no longer only provide access to textual webpages as part of the general search engine results pages (SERPs), but also to other representation formats, such as images and especially online videos, hereafter referred to as videos (Arguello, 2017; Azzopardi et al., 2018; Kammerer et al., 2018; Wopereis & van Merriënboer, 2011; also see Figure 1 for an example of a SERP from the present study). Therefore, it is not surprising that apart from using text-dominated webpages,

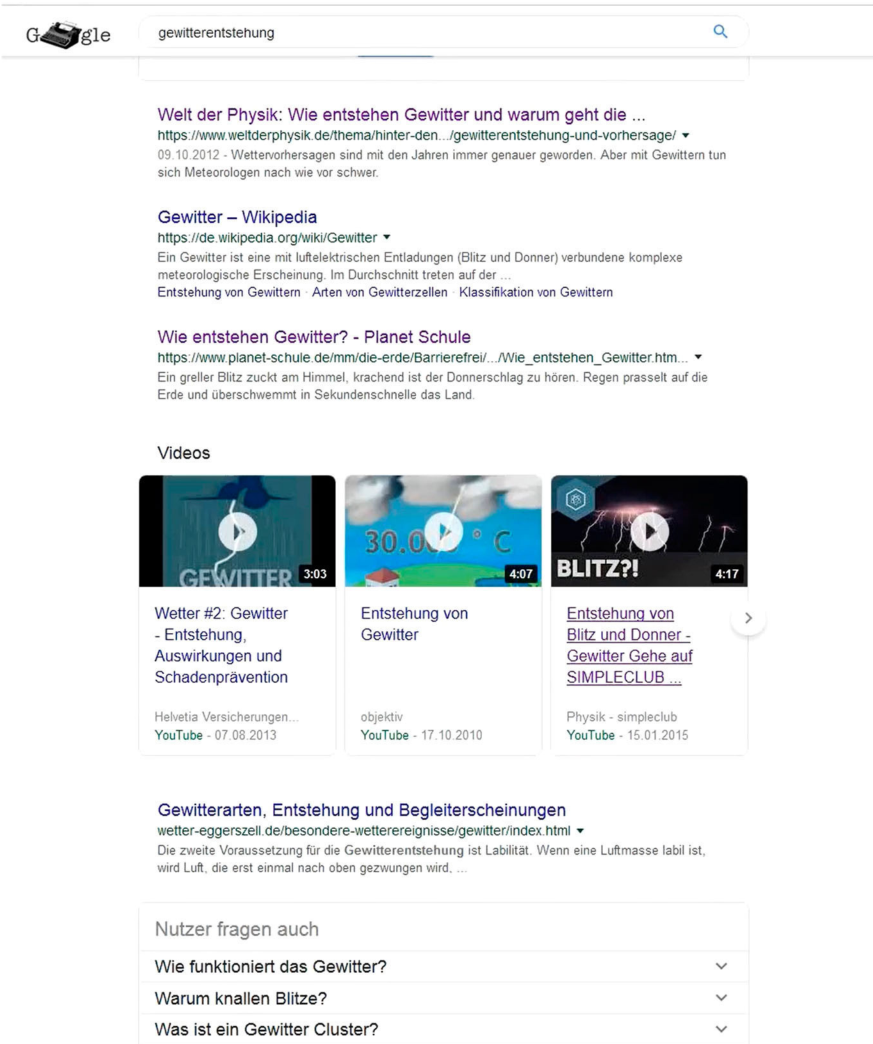

Figure 1. Example screenshot of a SERP for the query "gewitterentstehung" [thunderstorm formation] retrieved by a participant of the present study.

students report to increasingly use videos (e.g. from YouTube) for learning purposes (e.g. ACRL, 2015; Feierabend et al., 2020; Huang & Archer, 2017; Jebe et al., 2019; Koch & Beisch, 2020; Smith et al., 2018; for details see Section 1.1).

Theoretical models describing the process of web-search based learning (e.g. Brand-Gruwel et al., 2009; Frerejean et al., 2019; Gerjets et al., 2011; Kiili et al., 2018; Kuhlthau et al., 2008;) typically distinguish several iterative processing phases, such as: defining the information problem or learning goal (Phase 1); searching for and locating information, e.g. by using a search engine, and deciding which information resources to access (Phase 2); scanning and evaluating the information provided by the accessed resource (Phase 3); if deemed suitable processing the information more deeply and integrating it with prior knowledge and with information from other information resources (Phase 4); and, finally, synthesising the information and representing mentally or communicating in written or oral form what has been learned (Phase 5). However, little is known yet about how different representation formats, such as text, images, and video, contribute to this process of knowledge building while searching the web to learn about a particular topic.

The primary goal of the present study was to shed light on this issue to better understand how different representation formats are used for learning within the open web (cf. Garcia et al., 2021). To this end, 108 university students were asked to search the web freely in order to learn about the complex topic of how thunderstorms and lightning form. They were allowed to use any information resource they wanted. To analyse the degree of use of different kinds of representation formats, we recorded participants' eye movements, navigation logfiles, and HTML data of visited resources they wanted during their web search. We used a further refined version of the 'reading protocol' software (Hienert et al., 2019) that allows us to automatically assess fixation times on any text, image, or video content a participant retrieved. Thus, with our approach, we propose a possibility to automatically analyse areas of interest for web-search based learning sessions, as it recently has also been suggested by Schmidt et al. (2020). Furthermore, we were particularly interested in analysing from where the knowledge originated that participants acquired during web search. For this purpose, we mapped the textual content that participants processed on webpages (written text) and on videos (spoken text) to their essays that they composed about the inquired topic once before their web search (to assess their prior knowledge) and a second time after their web search (from memory).

In sum, with the present study, we aim to contribute a novel approach that allows to comprehensively analyse how learners use different representation formats during web-search based learning. With our approach, we take into account the request put forward by Wopereis and van Merriënboer (2011, p. 236; for a similar suggestion also see Greene et al., 2014) that "future research should consider the evolution of the web towards a predominantly multimedia-based information source."

1.1 The increasing use of videos for web-search based learning

A representative survey by Feierabend et al. (2020) about information-related Internet activities of German adolescents showed for the age group of 18–19 year olds that 62% indicated to use videos on YouTube "daily" or "at least several times a week" to inform themselves about a topic. Besides, 36% indicated to inform themselves "daily" or "at least several times a week" through Wikipedia and comparable websites, 30% through Twitter or Facebook, and 27% through news portals of online newspapers. Focusing specifically on the usage motives of online videos, Koch and Beisch (2020) found for a German sample between 14 and 29 years that 72% of those participants who reported to use YouTube at least once a month indicated to use YouTube "occasionally" to "frequently" to watch explanatory videos and tutorials. Similar results were obtained, for instance, in a recent U.S. representative survey, with 53% of 18–29 years old having reported in 2018 that YouTube was "very important" to them to figure out how to do things they have not done before (Smith et al., 2018).

To conclude, considering these survey results, the importance of videos for learning is clearly recognisable. A potential reason for using online videos for learning purposes is that learning with videos is perceived as easier and less demanding than learning with text materials (e.g. Salomon, 1984). At the same time, this, however, bears the risk of overestimating one's learning performance (e.g. Kardas & O'Brien, 2018). Yet, as we will outline in the following, empirical research on the actual use of online videos compared to other, mostly text-based information resources during web-search based learning is still scarce.

1.2 Learning with textual and video materials

Information resources on the web, such as webpages and videos, often comprise combinations of verbal (written or spoken) and pictorial (static or dynamic) representations (e.g. Mayer, 2017), with different representations being distributed across multiple information resources (e.g. Rouet & Britt, 2014). In his cognitive theory of multimedia learning, Mayer (e.g. 2014) describes how learners select, organise, and integrate verbal and pictorial information during learning. Based on Mayer's work, numerous studies have investigated in controlled experiments whether and, if so, how different representation formats, such as textual as compared to video representations, affect learning when the amount and structure of information is kept equal across representation formats. While some studies found that one format benefitted learning more than the other (e.g. Salmerón, Sampietro, et al., 2020; Schmidt-Weigand & Scheiter, 2011), other research did not find differences between videos and text-based materials regarding learning outcomes (e.g. Delgado et al., 2022; Gerjets et al., 2009; List, 2018; List & Ballenger, 2019; Merkt et al., 2011; Tarchi et al., 2021).

For instance, Schmidt-Weigand and Scheiter (2011) found that university students who were asked to learn with on-screen text perceived learning as more cognitively demanding than students who were provided with an animated video accompanied by on-screen text for their learning. In addition, when the on-screen text did not convey any spatial information, it resulted in inferior retention than when also having the video available. Salmerón, Sampietro et al. (2020) compared secondary-school students' comprehension and integration of information when learning with two textual webpages or with two "talking head" videos. Results showed that the videos were more persuasive than the textual webpages, such that after learning, students defended the views presented in the videos more than those presented on the webpages. Furthermore, participants who learned with the textual webpages better integrated information from the two information resources than those who learned with the videos.

In contrast, List (2018) found university students' comprehension and integration of information to be comparable regardless of whether they learned with two textual webpages or with two animated videos. However, the representation format influenced students' processing strategies. For example, students more frequently reported to consciously direct their attention towards the videos than towards the textual webpages, while they more frequently reported to identify the meaning of vocabulary in textual webpages than in videos.

Similarly, a recent study by Delgado et al. (2022) found no differences in secondary school students' metacognitive calibration and comprehension when learning with video blogs or text-based blogs. Tarchi et al. (2021) investigated undergraduate students' (immediate and delayed) learning outcomes after learning with a text, a video, or a subtitled video. They found no differences between representation formats for immediate testing. However, for a delayed transfer task (six weeks after the learning phase) that required solving tasks about different topics based on the learned content, students who had learned with the text outperformed those who had learned with the subtitled video.

To conclude, even in controlled settings, no clear advantage of one representation format over the other has been shown, and effects of textual as compared to video materials on learning might also depend on the concrete design and content of the learning materials. Thus, in the present research in which we examined web-search based learning in a natural setting with authentic information resources, it was not our goal to investigate which kinds of representation formats would be better or worse for learning. Instead, the main question was to explore to what extent learners *accessed* and *processed* different representation formats when they could choose between a large and heterogeneous set of webpages and videos, and from which information resources the knowledge originated that participants *acquired* during web search.

1.3 The role of different representation formats in web-search based learning

As outlined above, the process of learning with different representation formats has been investigated substantially in the research area of multimedia learning. Yet, the focus within research investigating students' learning with online information so far has been on textual resources (for recent overviews, see e.g. Kammerer et al., 2018; Zlatkin-Troitschanskaia et al., 2021). In contrast, the use of different representation formats has been only rarely addressed in prior scientific research on web-search based learning.

One recent study bringing together web-search based learning and different representation formats is a study by Andresen, Anmarkrud, and Bråten (2019). In their study, secondary-school students were provided with three webpages, each comprising a text, an image, and a video, to learn about the potential health effects of UV radiation. Learning outcomes were assessed as oral responses. The different representation formats (text, images, video) provided complementary information, which allowed the researchers to identify to what extent learners drew on information from the different representation formats in their oral responses. While the focus of the study was to examine differences between students with and without dyslexia, the results for students without dyslexia showed that most information reported in their oral responses originated from the texts, followed by information from the videos. Least information was drawn from the images. Linking this to the abovementioned phases of web-search based learning the study by Andresen, Anmarkrud, and Bråten (2019) provides first insights into Phase 5 (i.e. regarding the origin of the communicated learning outcome).

Furthermore, in a case study with four dyslexic students, Andresen, Anmarkrud, Salmerón et al. (2019) used the same web materials to explore in greater detail how (i.e. in what sequence and to what extent) the four students processed the different representation formats (text, image, video) on the three webpages. Analyses of eye-tracking and logfile data provided insights into Phase 4 of web-search based learning, that is, into the processing of information on the three webpages: The usage patterns differed across learners, with half of the learners first reading text, then viewing the image, and finally watching the video, while the other half of learners followed the linear structure of each webpage starting with watching a video (that was presented at top) followed by reading text and ending with inspecting the image.

The studies mentioned here, investigating the role of different representation formats, had in common that they were conducted with predefined materials instead of analysing search behaviour in an open, authentic setting. The same applies to most previous studies that focused on web-search based learning with (text-based) websites only, usually providing a set of up to 10 preselected and experimentally controlled websites (e.g. Brand-Gruwel et al., 2017; Mason et al., 2018; Salmerón, Delgado et al., 2020; only to mention a few recent examples). In the following, in contrast, we want to elaborate shortly on methodological approaches of investigating learners' web-search based learning in open, authentic web environments.

1.4 Methods of investigating learning in open web search environments

Methodologically, research investigating user behaviour during web-search based learning on the open web has often focused on capturing learners' interaction with search results and webpages by collecting logfiles (e.g. Câmara et al., 2021; Kalyani & Gadiraju, 2019; Kammerer et al., 2021; Knight et al., 2017; Liu et al., 2010; Marenzi & Zerr, 2012; Roy et al., 2020; Tibau et al., 2018; Yu et al., 2018) or recording gaze behaviour (e.g. Bhattacharya & Gwizdka, 2019; Gwizdka & Chang, 2020; Lewandowski & Kammerer, 2021).

An example of using logfiles for investigating web-search based learning is the work of Yu et al. (2018) which proposed a machine learning model to predict a user's prior knowledge and knowledge gain from 70 specific features, classifiable into session features, query features, SERP features, browsing features, and mouse movement features. Among the most promising features for predicting learning were time-based browsing features, such as maximum or average visit time per page. An example for using logfiles in actual teaching and learning contexts is the LearnWeb (Marenzi & Zerr, 2012), which is designed as a collaborative learning platform that allows monitoring learners' search activities and learning success through learning dashboards based on explicit (e.g. a glossary tool filled by the learner) and implicit measurements (e.g. tracking of queries and search activities). This monitoring allows to individually support learners during the web-search based learning process (Jaakonmäki et al., 2020).

Beyond the usage of log data, several researchers investigated different aspects of web-search based learning with the help of eye-tracking. Lewandowski and Kammerer (2021) provided a comprehensive review of previous research that used eye-tracking to investigate the viewing behaviour on SERPs (in controlled or authentic settings), which falls into the phase of searching for and locating information (i.e. Phase 2 of the web-search based learning process). An example of eye-tracking research that investigated how learners scanned and processed information in websites (Phases 3 and 4) they accessed during learning in an open web search context, is the work of Bhattacharya and Gwizdka (2019). They investigated in detail the reading behaviour of 30 participants performing web search tasks on several health-related topics. Their results showed that participants with higher knowledge gain had read significantly less on webpages but had entered more sophisticated queries than participants with lower knowledge gain.

In contrast to research especially investigating learning with textual and video materials, research investigating free web-search based learning has mostly neglected to consider the type of resources (text, video, or image) learners consult for learning. Moreover, the actual content of the visited web resources has also been neglected. In the present work, we argue that collecting and combining eye-tracking and logfile data, resource data (i.e. the accessed web contents, such as text and video transcripts), and essay data allow to investigate (1) to which extent learners use different representation formats (such as text and video) and (2) how different resources contribute to learning. This can be achieved by mapping and analysing the overlap between the content of visited web resources and participants' newly acquired knowledge as recalled in their post-search essays. We will elaborate on how we implemented this within our approach in the following.

1.5 The present study

In the present research, we tracked and analysed the resource usage (based on eye-tracking data and logfiles) and essay data of 108 university students learning about a complex natural science topic on the web. Generally, our approach (see Figure 2) includes the three steps of (1) data logging, (2) data processing, and (3) mapping. One main difference of our approach compared to most existing work is that beyond logfile and eye-tracking data, we also tracked the data of all visited resources, which enabled us to map newly learned knowledge (Phase 5 of the web-search based learning process) to the processing of the resources (Phase 4).

Specifically, by processing eye-tracking and resource data through a refined version of the 'reading protocol' software (Hienert et al., 2019), we generated a corpus of words that participants had read on websites. Additionally, we traced the words encountered in videos through video transcripts. Subsequently, we

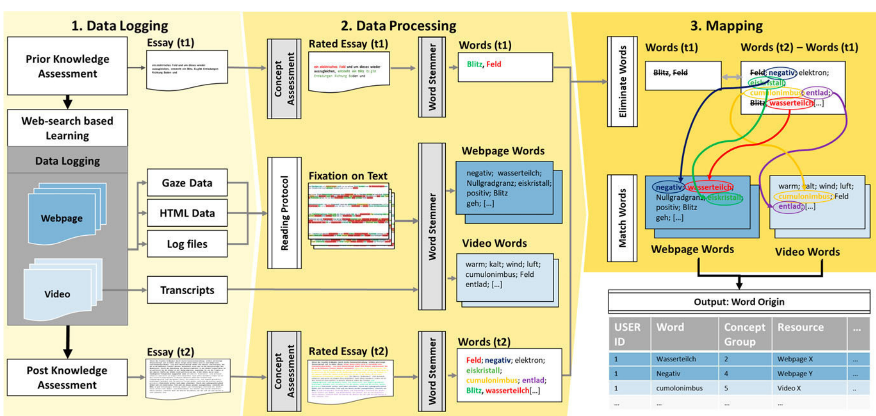

Figure 2. Procedure of retracing words from essay (t2) to visited webpage and video resources.

analysed the overlap between the corpus of encountered words and information recalled in the essays. This enabled us to determine which resources and words processed during web-search based learning participants subsequently also used (i.e. recalled from memory) in their post-search essays.

Further, as our first research question (**RQ1**), we explored to what extent (and how many different) webpages (with text and images) and videos students accessed during web search (Phase 2 of the models outlined in the introduction). As our second research question (**RQ2**), we analysed the extent to which students processed text, images, and video content during web search (Phase 4). Finally, as a third research question (**RQ3**), we investigated to what extent (and from which information resources) students incorporated (i.e. recalled from memory) information from text and from video content in their final essay, in which they summarised what they had learned about the topic (Phase 5).

2. Method

2.1 Participants

Participants were 130 university students from different majors at a large German university, who were compensated with 16€ for their participation. Due to technical problems during data recordings and other issues (e.g. misunderstanding the instructions), data from 15 participants had to be excluded from the dataset. Additionally, we excluded the data of another seven participants due to insufficient tracking ratios (< 80%) of the eye-tracking recordings. The final dataset for the analyses consisted of 108 participants (85.19% female; $M = 22.81$ years; $SD = 2.83$). Fifty-eight participants studied a social science major (e.g. educational science), 30 participants were from a humanities major (e.g. language studies, literature studies), and 20 participants from a natural science major (e.g. physics, medicine). Participants indicated to use the internet on average 32.02 h per week ($SD = 14.90$, scale from 1 to 70 h). Regarding participants' familiarity with search engines, they indicated on a scale ranging from "1 = not at all" to "5 = totally", that they felt quite proficient in using search engines to find suitable information ($M = 3.86$, $SD = 0.88$; "I know how to use search engines to find suitable information"). Participants' prior knowledge on the formation of thunderstorms and lightning was rather low, as indicated by the low number of correct concepts ($M = 1.75$, $SD = 1.80$, out of 20 concepts) included in their (t1) essay written before starting their web search (also see Section 3.3). Students from natural science majors reached a significantly ($F(2, 105) = 4.50$, $p = .009$) higher prior knowledge score ($M = 2.85$ concepts, $SD = 2.94$) compared to students from humanities ($M = 1.50$ concepts, $SD = 1.01$) or social science majors ($M = 1.50$, $SD = 1.48$). Beyond that, however, no significant differences were found between natural science, social science, and humanities majors, regarding any of the assessed measures (such as, the number of concepts in essay (t2), the number of words in essay (t1) and essay (t2), total session time, or fixation times on text or videos).

2.2 Task

Participants were asked to learn with the help of the web as much as possible about the formation of thunderstorms and lightning. This topic is complex and requires knowledge about different physical and meteorological concepts and their interactions. Participants had a maximum of 30 min for their web-search based learning but could also quit the task earlier. Before and after this learning phase, participants were asked to write an essay in which they were asked to explain how thunderstorms and lightning form as detailed as possible.

2.3 Data logging and data processing

For the first step of data logging (see Figure 2) we used the SMI Experiment-Center 3.7 to record participants' eye movements. The software records gaze data and navigation logfiles. Collected raw data was exported with SMI BeGaze 3.59. To capture all webpages that participants visited in an HTML format, we installed the plugins "ScrapbookX" (1.5.14)[1] and "ScrapbookXAutosave" (1.4.3)[2] within the given Mozilla Firefox Browser (ESR 45.6.0). Each visit of a webpage automatically triggered an imperceptible download process of the necessary files to reconstruct the webpage. For the step of data processing, a refined version of the 'reading protocol' software (Hienert et al., 2019) was used to connect and analyse the collected gaze data and resource data (i.e. the HTML-files). In the reading protocol, raw eye-tracking data (x and y coordinates) are defined as fixations or saccades based on an ID-T algorithm (Salvucci & Goldberg, 2000). The software allows to analyse on any HTML page which parts of the page have been viewed and read by a participant and to calculate participants' total fixation times on text parts, such as words, sentences, or paragraphs, and in the refined version, now also on images and videos. For fixation times on the text and images, we added up all fixation durations on words or images, respectively, across all webpages. The time spent viewing videos comprised the time participants fixated HTML-video elements on YouTube videos and other embedded videos.

The graphical frontend of the 'reading protocol' software (see Figure 3) offers the possibility to illustrate the word-eye-fixations on all read webpages as a heat map. These heatmap visualisations can be displayed for individual participants or accumulated across all participants reading the particular webpage (example data: https://vizgr.org/nrhm_2021).

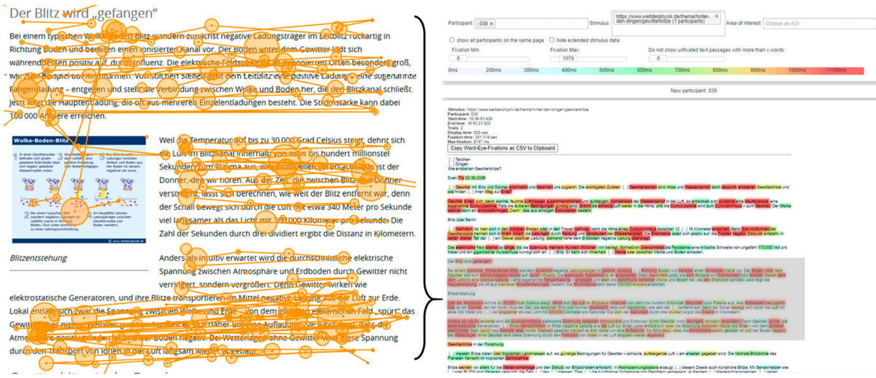

Figure 3. Scan path (from SMI BeGaze) of one participant for a section of the information resource https://www.weltderphysik.de/(...)/gewitterblitze-[…] (left) and the corresponding reading protocol data in the graphical frontend (right).

2.4 Coding system to assess pre- and post-knowledge

To assess participants' pre- and post-knowledge, both essay (t1) and essay (t2) were analysed based on a coding scheme which we developed in an iterative process based on a previous coding scheme by Schmidt-Weigand and Scheiter (2011). Our final coding scheme contained nine concept groups consisting of 20 concepts (see Table 1) that were all related to different aspects of the formation of thunderstorms and lightning. The more concepts a student had correctly addressed in their essay, the more comprehensive was their overall understanding of the formation of thunderstorms and lightning.

Each essay was scored according to the 20 concepts, which allowed to determine the respective concept group they belonged to. A concept was scored as present when a correct conceptual understanding of that concept could be noticed (e.g. "clouds are formed by condensation of humidity into water drops in the air"). Since concepts can be described within or across sentences, we coded on the level of idea units representing the concept, not on a sentence level. Two independent raters coded 55 essays. The overall agreement between the two raters was 95.8%, and the average Cohen's kappa across all concepts was κ .84. Disagreements were resolved through discussion between the raters. Subsequently, one rater coded the remaining essays.

2.5 Mapping essay data to information resources

Since we did not index images regarding their conceptual content, we were not able to map learned concepts to viewed images. For text and video contents, we applied the following steps for each participant: First, based on the coding of the individual concepts (see Table 1), all segments in participants' essay (t1) and

Table 1. Coding scheme with nine concept groups and 20 concepts to assess students' conceptual understanding of how thunderstorms and lightning form.

No.	Concept group	Concepts
1.	Convection	Heating of the soil
		Presence of moist warm air
		Ascent of air
2.	Condensation	Cloud formation due to condensation
		Additional ascent of air due to condensation
3.	Air circulation	Air flows within the cloud
4.	Cloud characteristics	Cloud shape and height
5.	Icing phase	Ice crystals formation and freezing zone within the cloud
6.	Thunderstorm electricity	Origin of electric charge
		Friction and collision of particles within the cloud (ice and water)
		Charge distribution within the cloud
		Electric potential between earth and cloud
		Electrostatic influence
7.	Pre-discharge	Pre-discharge
		Formation of ionised channel
		Upward streamers
8.	Main discharge	Charge equalisation
9.	Other aspects	Explanation flash of light
		Explanation of thunder
		Different lightning types

(t2) belonging to the same concept group were rated and marked with the same colour (see Figure 2, Data Processing). All words from the rated essays were then stemmed (Porter, 2001).

Next, as preparation for the mapping process, all words which had already been used in essay (t1), as well as stop words, words with less than four characters, and special characters, were eliminated from essay (t2). All remaining words then were registered in a list of words, together with information about the concept group they belonged to (see Figure 2, Mapping). This also informed about the most used words for each respective concept group.

Second, the reading protocol allowed us to create a list of all words that a participant had fixated on webpages (based on the extracted HTML-files). Only words fixated for at least 150 ms were included in our word analyses, which according to the E-Z reader model, represents the lower bound for lexical access (Reichle et al., 2009). For visited videos, the reading protocol provided us with the total fixation time on the video frame but not the concrete fixations on content. Therefore, instead, the transcripts offered by YouTube were crawled, checked, and corrected manually if necessary. For videos without available transcripts we manually generated the video transcripts. The encountered words across all visited resources (webpages and video transcripts of viewed videos) were then stemmed and summarised for each participant. Finally, we compared essay words (t2) with all stemmed words per information resource. As a result, we generated a list of word origins where we retraced the words and the associated concept groups of essay (t2) to particular information resources.

2.6 Procedure

Participants were tested in an eye-tracking lab in group sessions of up to four participants that lasted approximately one hour. Each participant had an individual workplace. The workplace consisted of a desk with a laptop connected to a 24-inch screen (1920 × 1080px), linked to a mouse and a keyboard. Below the screen, an SMI (Senso Motoric Instruments) RED250mobile eye-tracking device was attached. After participants were informed about the general procedure, they were positioned on a chin rest in front of the eye tracker. All subsequent steps in the experiment were displayed to the participants on the laptop and processed there.

First, they were asked to write an initial essay (t1) in which they should write down everything they knew about the formation of thunderstorms and lightning. There were no time restrictions or limitations on text length. After completing essay (t1), participants were informed that their task was to conduct a web search to learn about the formation of thunderstorms and lightning and that afterwards, they would have to explain everything they had learned about it to the other participants in the room. This was stated to generate a higher motivation to learn for the participants. In the debriefing, it was resolved that they did not need to explain the topic to other participants. Participants were also encouraged to use any kind of and as many information resources as they wanted.

Then, participants were calibrated on the eye-tracking system using a 9-point calibration, and subsequently started the web-search based learning phase. Participants were provided with access to the internet via the Mozilla Firefox browser (ESR 45.6.0), with the browser cache being cleared for each participant. The starting point for every participant was the Google search engine.

During the whole web-search based learning phase, the screen and eye movements of the participants were recorded with the SMI ExperimentCenter 3.7 software. After having terminated their web search, participants were asked to write another essay (t2) by writing down everything they now knew about the topic. Beyond the measurements reported above, a multiple-choice knowledge test (see von Hoyer et al., 2019; Otto et al., 2021) as well as participants' working memory capacity and reading comprehension skills (see Pardi et al., 2020) were also assessed in the course of this study, which, however, are beyond the scope of the present paper.

3. Results

3.1 Extent of accessing webpages and videos

Overall, participants, on average, spent 25.47 min ($SD = 6.59$) on the web-search based learning task. All but one participant viewed Google SERPs ($M = 12.95$ SERPs, $SD = 10.34$) and spent an average of 2.53 min there ($SD =$

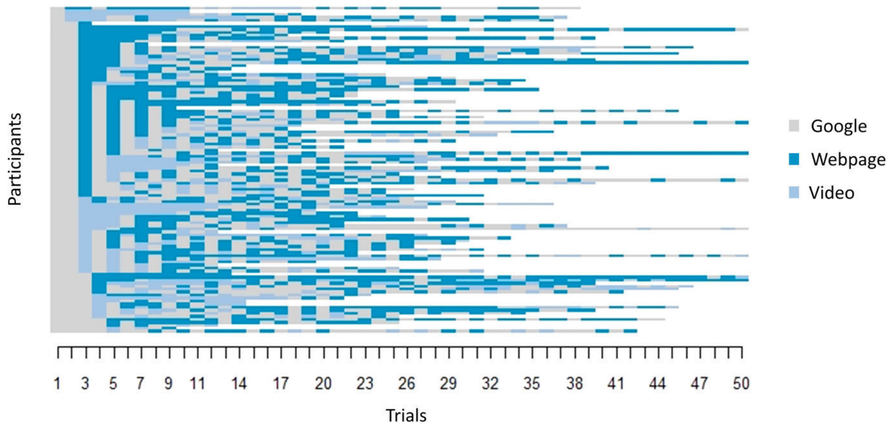

Figure 4. Sequence (trials 1–50) of visited resource types across the 108 participants (1 participant per row) clustered from the start.

2.34). Four participants went directly to YouTube. To address our RQ1, we analysed which content pages participants accessed during their web-search based learning session. In general, across the 108 participants, 239 distinct content resources were accessed. These consisted of 194 textual webpages (from 95 different website domains) and 46 different videos (41 from YouTube, 5 that were incorporated into textual webpages). Figure 4 illustrates the sequences 1–50 (participants had an average sequence length of $M = 29.89$, $SD = 15.92$) in which the 108 participants were accessing Google services, websites, and videos over time (1 participant per row).

Participants visited $M = 6.81$ ($SD = 3.97$, $min = 1$, $max = 22$) different textual webpages, from $M = 5.21$ ($SD = 2.74$) different website domains. For instance, 59 (54.63%) participants visited Wikipedia pages. Furthermore, the majority (91 participants, 84.26%) viewed at least one video. Those 91 participants viewed an average of $M = 3.29$ ($SD = 1.80$, $min = 1$, $max = 8$) different videos. Table A1 (Appendix) gives an overview of the 10 most visited information resources (SERPs were not classified as information resources). Noteworthy, all of those information resources addressed the formation of thunderstorms and lightning and had educational characteristics.

3.2 Extent of processing text, video, and image representations

Regarding RQ2, we analysed across all 108 participants how they devoted their reading and viewing times to text, video, and images. Only content-related webpages (Google-domains excluded) and videos were considered for the following analyses. Figure 5 shows the distribution for the 108 participants with the lengths of viewing times in a stocked bar chart. Each bar represents the measured total fixation time of a participant on text, video, and image representations, arranged in descending order of total fixation time on text.

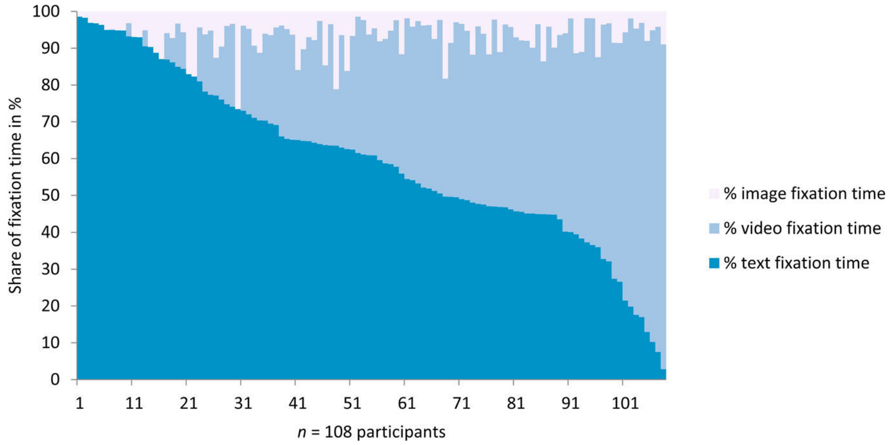

Figure 5. Share of fixation time (in %) for text, video, and images.

Averaged across all 108 participants, the total fixation time on text was dominant with *M* = 441.27 s per participant (*SD* = 234.96, *min* = 6.27 s, *max* = 1035.70 s) followed by *M* = 342.61 s (*SD* = 258.69, *min* = 0, *max* = 1,202.59) of video fixation time. Finally, images were fixated for *M* = 72.13 s (*SD* = 55.94, *min* = 1.18 s, *max* = 313.20 s). Pairwise comparisons (Bonferroni-corrected) showed that these time differences between the three representation formats all were significant (all $p < .001$). As shown in Figure 5, the largest share of fixation time was devoted to text (*M* = 54.39%, *SD* = 24.81), followed by video fixation time (*M* = 38.99%, *SD* = 25.54). In sum, 59 participants (54.63%) spent more than 50% of their fixation time on text, while only 43 participants (39.81%) spent more than 50% of their fixation time on video. The share of image fixation time (*M* = 6.61%, *SD* = 5.01) played a minor role among participants.

3.3 Differences between essay (t1) and essay (t2)

Before addressing RQ3 concerning the origin of learned content, in the following, we will first report on the extent of knowledge that participants acquired through their web-search based learning. The essay written before their web-search based learning (t1) represented participants' prior knowledge and the essay written afterwards (t2) their acquired knowledge, respectively. As shown in Table 2, the number of written words (not stemmed), scored

Table 2. Means (and standard deviations) for number of words, scored concepts, and concept groups in essay (t1) and essay (t2) and inferential statistics.

	Essay (t1)	Essay (t2)	Inferential statistics
# words (not stemmed)	41.80 (28.98)	200.15 (72.83)	$t(107) = 23.94$, $p < .001$
# scored concepts	1.75 (1.80)	9.32 (2.60)	$t(107) = 27.73$, $p < .001$
# scored concept groups	1.54 (1.35)	5.08 (1.45)	$t(107) = 21.84$, $p < .001$

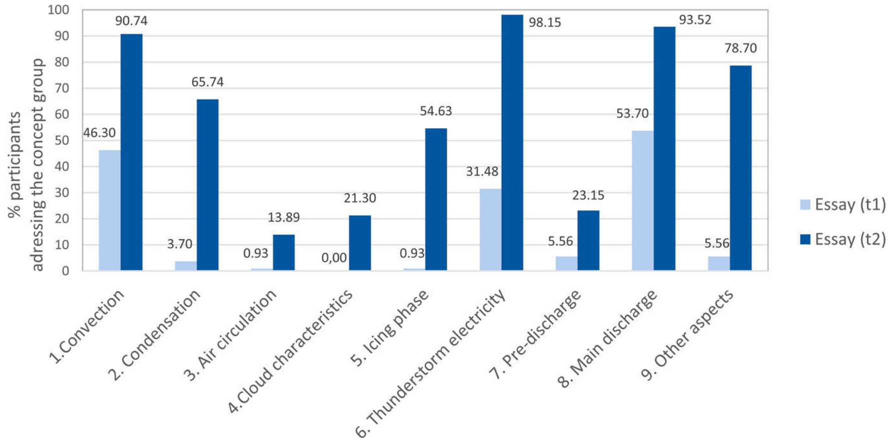

Figure 6. Percentage of participants addressing the nine concept groups in essay (t1) and essay (t2).

concepts, and concepts groups increased significantly from essay (t1) to essay (t2). Furthermore, Figure 6 shows the percentage of participants who referred to the different concept groups in essay (t1) and essay (t2), indicating substantially higher percentages for almost all concept groups in the post-search essay. At the same time, it can be seen that the concept groups addressing air circulation in clouds, cloud characteristics, or pre-discharge of lightning were only addressed by a few participants.

3.4 Used representation formats and word origin

Concerning our RQ3, we analysed the percentage of words from essay (t2) that we could also find in the fixated text on webpages and/or in transcripts of viewed videos. In sum, for all 107 participants who visited at least one textual webpage, words from essay (t2) could be retraced to fixated text. Likewise, for all 91 participants who viewed at least one video, words from essay (t2) could be retraced to video content. Across all 108 participants, an average of 68.52 stemmed words ($SD = 22.20$) were extracted from participants essay (t2). From these words, $M = 10.36$ words ($SD = 5.88$), representing 15.54%, could be matched to stemmed words of essay (t1) and were excluded for further analysis. For the remaining stemmed words ($M = 58.16$, $SD = 19.73$), an average of 79.94% ($SD = 9.90$) could be retraced either to fixated text or to video transcripts of viewed videos, while only $M = 20.06\%$ ($SD = 9.89$) could not be retraced to visited resources.

Looking more closely at the match between stemmed words from essay (t2) and words found in fixated text or in video transcripts (across all 108 participants), a significantly higher percentage ($t(107) = 4.75$, $p < .001$) of words from participants' post-search essays (t2) could be retraced to fixated text (M

= 65.85%, $SD = 17.10$) than to video transcripts ($M = 50.56\%$, $SD = 25.40$). When only considering those 90 participants who had viewed at least one webpage and at least one video, an average of 65.41% of essay (t2) words ($SD = 16.16$) could be retraced to text and $M = 59.89\%$ ($SD = 14.13$) to video transcripts, which represents a significant difference ($t(89) = 2.28$, $p = .025$).

3.5 The origin of different concept groups

Finally, we analysed from which representation format (i.e. text, video) and from which information resources (i.e. concrete webpages and videos) the words connected to learned concept groups potentially originated. Therefore, we compared words falling into concept group annotations and compared them to fixated text and to the transcripts of viewed videos. As before, words that had already been included in essay (t1) were not considered in these analyses. The five most commonly used words per concept group that participants included in their essay (t2) are provided in Table A2 (Appendix). For each concept group, we calculated the average number of words fixated in text for at least 150 ms and/or included in transcripts of viewed videos (see Figure 7). As a result, we identified 106 (out of 107) participants who incorporated words in essay (t2) from fixated text, 91 (out of 91) participants from video content, and 89 (out of 90) participants from both.

As can be seen in Figure 7, when only considering those participants who had visited at least one webpage or at least one video, respectively, for most concept groups, a similar number of words could be retraced to text and to video content (as indicated by the ‘text’ bars and the ‘video’ bars). Moreover, a considerable amount of words could be retraced to both text and video

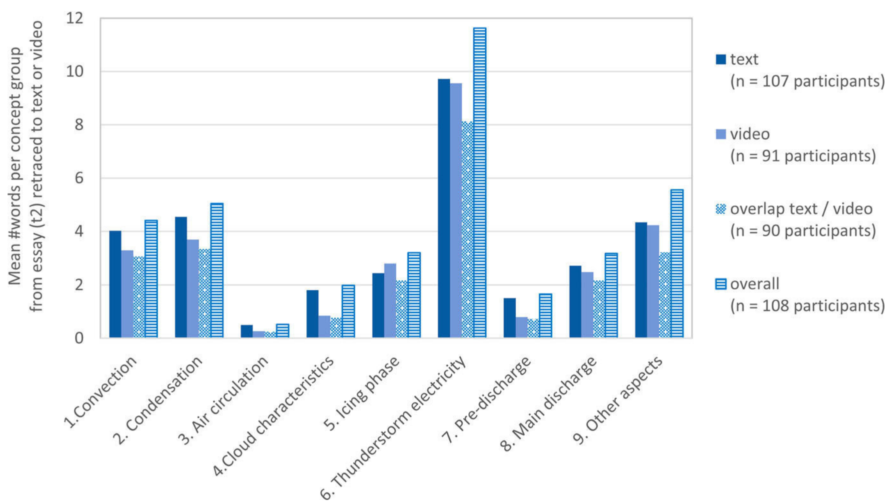

Figure 7. Average number of words from essay (t2) retraced to fixated text or video transcripts of viewed videos.

content (as indicated by the ‘overlap’ bars). However, to a smaller extent, text and video also contributed different words to the respective concept groups (as indicated, for instance, by the differences between the ‘overall’ bars and the ‘text’ bars or the ‘video’ bars, respectively).

In addition, our approach also allowed us to retrace words for each scored concept group to specific information resources (i.e. specific webpages and videos). Figure 8 shows the average number of words per concept group that participants had come across in the top three webpages (only considering participants who had visited the respective webpage) and subsequently used in their essay (t2). Among the nine concept groups, the highest number of matched words was found for concept group #6, “Thunderstorm Electricity”, which was also the most complex group comprising five different concepts. The results further indicate that the three webpages contributed to a different extent to the acquisition of specific concept groups. For instance, the first ‘world of physics’ webpage seemed to contribute more to concept groups #2 and #4, whereas both the ‘planet school’ webpage and the second ‘world of physics’ webpage contributed more to concept group #6.

We used the video transcripts to analyse the overlap between words in essay (t2) related to the nine concept groups and words included in viewed videos. Figure 9 shows the average number of words per concept group that participants potentially had come across in the top three videos (only considering participants who visited the respective video). Again, the highest number of matched words among the nine concept groups was found for concept group #6 “Thunderstorm Electricity”. Furthermore, as for the webpages, the results indicate that the three videos contributed to a different extent to the acquisition

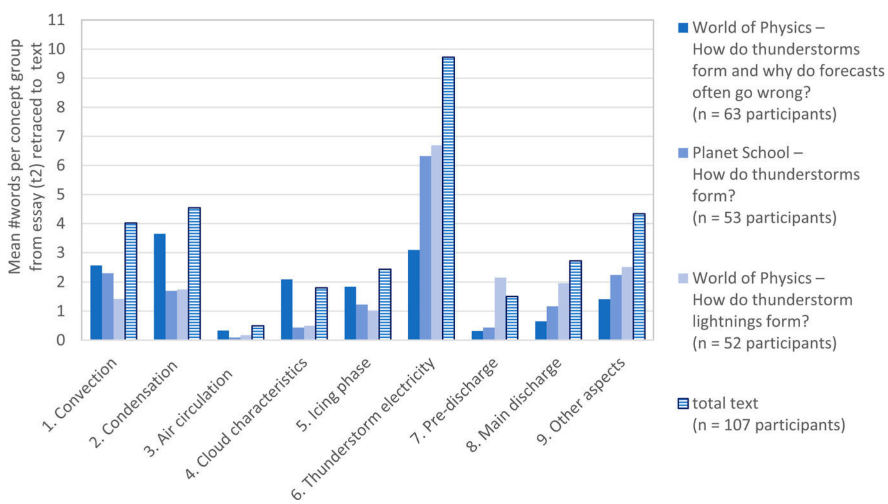

Figure 8. Average number of words from essay (t2) retraced to fixated text (overall or in the three most visited webpages, respectively) as a function of concept group.

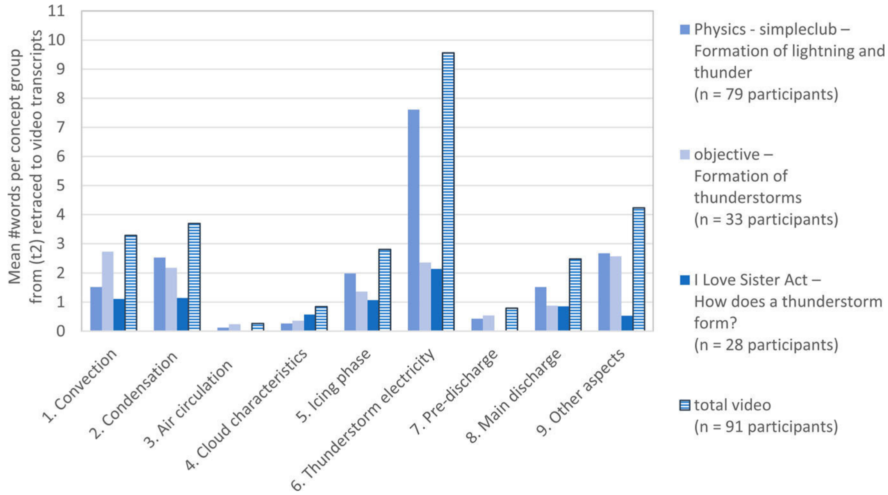

Figure 9. Average number of words from essay (t2) retraced to video transcripts (of viewed videos overall or the three most visited videos, respectively) as a function of concept group.

of specific concept groups. Particularly for concept group #6, the video from 'Physics—simpleclub' had the largest contribution.

4. Discussion and conclusion

To our knowledge, the present work is the first investigating in detail (a) the use of text and video resources and (b) how different resources contributed to knowledge construction in an open, authentic web environment. This could only be achieved through our new approach of combining logfile, eye-tracking, and resource data, which enabled us to map newly learned knowledge represented within essays (Phase 5) to information that was processed in different resources during web-search based learning (Phase 4). Thus, our approach contributes to the recently raised research question by Zlatkin-Troitschanskaia et al. (2021) regarding how students use online resources and information for domain-related learning on the web.

Concerning RQ1 (i.e. the extent to which webpages and videos were accessed; Phase 2 of the process of web-search based learning), we found that nearly twice as many webpages as videos were accessed during students' web-search based learning. Thus, for the students of the present study, webpages in general seemed to play a major role as information resources to learn about the formation of thunderstorms and lightning. Nevertheless, in line with the results of recent surveys (e.g. Feierabend et al., 2020; Koch & Beisch, 2020; Smith et al., 2018), videos, mainly from YouTube, also played a considerable role: Students, on average, viewed more than two videos and the list of the 10 most visited information resources was led by a YouTube video (and also included two more YouTube videos). Noteworthy, our results also showed that with 194 distinct webpages and 46 different videos being visited by the 108 participants, learners seemed to select different resources rather than everyone using the same few information resources (e.g. Wikipedia).

Concerning RQ2 (i.e. the extent to which text, image, and video representations were processed; Phase 4), our results provide first insights into the actual extent of usage of different representation formats during web-search based learning. Taking the overall fixation time as an indicator for processing content, in line with the findings regarding the number of visited webpages, the results showed that participants fixated on average considerably longer on text (441.27 s) than on video content (342.61 s). Furthermore, images (72.13 s) played a rather subordinate role in students' web-search based learning.

With regard to RQ3 (i.e. the extent to which content from text and video was incorporated in students' final essay after learning; Phase 5), first of all, our results showed that participants included more correct concepts in their post-search essays than in their pre-search essays. Thus, by searching the web, learners managed to extend their conceptual knowledge about the respective topic and communicate it in their post-search essay. Furthermore, with our analyses, we were able to identify from which resources newly acquired knowledge potentially originated. Specifically, we retraced words from participants' post-search essays to words found in text or video transcripts of resources that participants had visited. These analyses revealed that a substantial degree of words addressing different concept groups could be retraced to the three most visited webpages and videos. Furthermore, we were able to map about 66% of the words learners used for the first time in their post-search essay to text they had processed during their web-search based learning and about 51% to videos. These findings align with the results of Andresen, Anmarkrud, and Bråten (2019), who also found an advantage for text as a source of information compared to video.

As a first limitation of the present work, however, it should be acknowledged that we based the matching of essay words to the contents of the viewed videos on the video transcripts of the complete videos. Thus, on the one hand, the number of matched words obtained from our analyses might overestimate the actual encountered words because we cannot exclude that some participants actually did not watch the complete videos. On the other hand, however, our analyses ignored any content that was only addressed visually in the videos but not in spoken text. Likewise, we did not analyse content encountered in images in the present work. Future research could combine our approach with automatic video (e.g. Ewerth et al., 2012) and image content (e.g. Otto et al., 2019) analysis methods.

As a second limitation it should be mentioned that for our analyses concerning concepts we only coded correct statements. Future research could expand our approach by coding incorrect statements and analysing from which information resources those statements potentially originated. Furthermore, while we concentrated on analysing which resources contributed to the different concepts within the essays, future work could also analyse other aspects of the essays, such as argumentation quality (e.g. Brand-Gruwel et al., 2005; Whitelock-Wainwright et al., 2020) and how it relates to the extent of using websites or videos. However, we believe this would be more relevant when investigating web-search based learning regarding conflicting topics (e.g. Greene et al., 2014, 2018). Moreover, further research is needed to extend our findings to other learning topics and knowledge types (e.g. procedural knowledge). Indeed, it is reasonable to assume that learning with online videos will play an even more important role when learning how to perform a new sensorimotor procedure (e.g. Bétrancourt & Benetos, 2018).

Furthermore, our approach could also be applied to more prolonged and even multi-sessional endeavours of web-search based learning. In this context, longer time intervals between participants' web search and the assessment of their learning could be beneficial to analyse differences between immediate recall after the task and long-term learning (cf. Tarchi et al., 2021). Also, effects of note-taking could be examined (cf. Delgado et al., 2022). Further, by using our approach, future work could also gain additional insights into how learning evolves during a web-search-based learning session (Roy et al., 2020) and how different resources contributed to it. Likewise, our approach could also be applied to SERP viewing to examine which of the words or concepts they fixated in the search results (cf. Taibi et al., 2017) were later recalled in their essays.

A final limitation of the present work is that, even though students from natural science majors had a somewhat higher prior knowledge on the topic than students from humanities and social science majors, we examined a rather homogeneous sample of university students with rather low prior knowledge on the task at hand, but quite high experience in conducting web searches for learning purposes. In contrast, future studies could use our approach to investigate web-search based learning in more heterogeneous samples, for instance, to investigate differences in web search behaviour between domain experts and novices (cf. Brand-Gruwel et al., 2017) or between search experts and novices, respectively, in terms of their usage of different representation formats and how information from these resources was subsequently recalled in their learning products.

Notwithstanding the abovementioned limitations, we believe that our new methodological approach offers great potential to investigate web-search based learning processes, especially on the open, authentic web. Still, it could also be used in experimental environments with prepared sets of resources. It can provide valuable insights into which resources, and particularly which passages, were consulted and subsequently recalled by students in their writing.

While our approach is considered as a research tool in the first place, in the future, it might also help teachers to find out, for instance, which resources were consulted and which information was subsequently used or recalled by those students who performed best in the assigned learning task. Given this information, teachers could recommend struggling learners suitable resources or determine whether they had already consulted those resources but concentrated on the wrong passages or whether they had even read the correct passages but still did not use the information in their learning product. In addition, passages that contributed to learning for good learners could be automatically highlighted to guide poorer learners' attention to relevant content, for example, in learning environments such as the LearnWeb (Jaakonmäki et al., 2020).

In conclusion, to our knowledge, this is the first study that provides detailed insights about how and to what extent learners use textual and video resources in a free web environment and what they subsequently recall and understand from these resources. In sum, our results show that to learn about the formation of thunderstorms and lightning, the majority of the examined university students used both textual and video resources to a considerable extent.

Notes

1. https://github.com/danny0838/firefox-scrapbook
2. https://github.com/danny0838/firefox-scrapbook-autosave

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix

Table A1. Overview of the 10 most visited information resources (only resource URLs considered, no SERPs or service Google pages included).

No.	URL	Source (Translation)	Title (Translation)	# Participants visiting	*M (SD)* of viewing time per participant (in minutes)[a]	*M (SD)* of viewing time per participant (in %)[a]	Overall viewing time across all participants (in hours) [a]
1	https://www.youtube.com/watch?v=BGDVGWhknwk	YouTube channel: Physik – simpleclub (Physics – simpleclub)	Entstehung von Blitz und Donner (Formation of lightning and thunder)	79	5.67 (4.08)	22.09 (15.99)	7.47
2	https://www.weltderphysik.de/thema/hinter-den-dingen/gewitterentstehung-und-vorhersage/	Welt der Physik (World of Physics)	Wie entstehen Gewitter und warum geht die Vorhersage oft schief? (How do thunderstorms form and why do forecasts often go wrong?)	63	3.13 (2.58)	11.96 (9.75)	3.29
3	https://www.planet-schule.de/mm/die-erde/Barrierefrei/pages/Wie_entstehen_Gewitter.html	Planet Schule (Planet School)	Wie entstehen Gewitter? (How do thunderstorms form?)	54	1.97 (1.12)	7.71 (4.53)	1.78
4	https://www.weltderphysik.de/thema/hinter-den-dingen/gewitterblitze/	Welt der Physik (World of Physics)	Wie entstehen Gewitterblitze? (How do thunderstorm lightnings form?)	52	4.38 (3.85)	17.87 (14.94)	3.80
5	https://de.wikipedia.org/wiki/Gewitter	Wikipedia	Gewitter (Thunderstorm)	47	3.55 (2.53)	13.11 (10.10)	2.63
6	https://www.wissenschaft-im-dialog.de/projekte/wieso/artikel/beitrag/wie-entstehen-blitz-und-donner/	Wissenschaft im Dialog (Science in Dialog)	Wie entstehen Gewitter? (How do thunderstorms form)	43	1.55 (1.13)	6.58 (5.33)	1.12
7	https://www.youtube.com/watch?v=wO-NL8Bbu_c	YouTube channel: objektiv (objective)	Entstehung von Gewitter (Formation of thunderstorms)	33	2.98 (1.72)	10.53 (6.14)	1.64
8	https://de.wikipedia.org/wiki/Blitz	Wikipedia	Blitz (Lightning)	32	2.87 (3.37)	10.96 (12.61)	1.54
9	https://www.nela-forscht.de/2011/06/08/wie-entsteht-ein-gewitter	Nela forscht (Nela investigates)	Wie entsteht ein Gewitter? (How does a thunderstorm form?)	32	2.98 (3.68)	12.13 (17.23)	1.60
10	https://www.youtube.com/watch?v=KzB-X4AIuE8	YouTube channel: Ilovesisteract (I love Sister Act)	Wie entsteht Gewitter? (How does a thunderstorm form?)	28	1.82 (0.53)	8.36 (4.45)	0.86

[a]Only includes participants who accessed the information resource.

Table A2. Overview of the 5 most used (stemmed) words in German (English translation in parentheses) per concept group as well as the average number of found words per concept group (overall, in text, in video, in text & video).

No.	Concept group		1	2	3	4	5	*M* (*SD*) overall ($n = 108$)	*M* (*SD*) text ($n = 107$)	*M* (*SD*) video ($n = 91$)	*M* (*SD*) overlap text / video ($n = 90$)
1	Convection	#participants	44	38	27	26	18	4.25 (3.00)	3.87 (2.80)	3.29 (2.76)	2.97 (2.39)
		word	steigt (rises)	feucht (moist)	oben (above)	warm (warm)	wasserdampf (water steam)				
2	Condensation	#participants	31	22	20	20	19	4.86 (4.88)	4.35 (4.41)	3.75 (3.71)	3.07 (3.10)
		word	kondensiert (condenses)	wasserdampf (water steam)	energi (energy)	wassertröpfch (water droplets)	kondensation (condensation)				
3	Air circulation	#participants	9	4	2	2	2	0.50 (1.45)	0.47 (1.35)	0.26 (1.05)	0.22 (0.93)
		word	aufwind (upwind)	stark (strong)	eiskristall (ice crystal)	gewitterwolk (thundercloud)	luft (air)				
4	Cloud characteristics	#participants	10	9	7	7	7	1.83 (4.41)	1.70 (4.08)	0.85 (2.36)	0.66 (1.95)
		word	stratosphär (stratosphere)	horizontal (horizontal)	gewitterwolk (thundercloud)	grenz (border)	tropopause (tropopause)				
5	Icing phase	#participants	31	28	17	15	15	3.09 (3.42)	2.35 (2.70)	2.80 (3.02)	1.91 (2.14)
		word	gefri (freeze)	eiskristall (ice crystal)	wolk (cloud)	nullgradgrenz (zero degree limit)	wassertröpfch (water droplets)				
6	Thunderstorm electricity	#participants	86	85	75	56	40	11.18 (4.56)	9.32 (4.34)	9.56 (4.03)	6.48 (3.33)
		word	negativ (negative)	positiv (positive)	unt (below)	gelad (loaded)	wolk (cloud)				
7	Pre-discharge	#participants	11	9	8	7	7	1.58 (3.34)	1.46 (3.24)	0.79 (1.84)	0.63 (1.61)
		word	negative (negative)	blitzkanal (lightning channel)	positive (positive)	kanal (channel)	leitblitz (lead lightning)				
8	Main discharge	#participants	24	19	15	14	13	3.05 (2.52)	2.62 (2.47)	2.48 (2.02)	1.97 (1.91)
		word	spannung (voltage)	entlad (discharge)	kommt (comes)	blitz (lightning)	entlädt (discharge)				
9	Other aspects	#participants	38	26	21	21	18	5.23 (4.22)	4.06 (3.70)	4.23 (3.35)	2.82 (2.50)
		word	donn (thunder)	luft (air)	dehnt (stretches)	schnell (fast)	erde (ground)				

Appendix B: Manuscript 2 (Experiments 2 and 3)
The following is the published article under:

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The moderating effect of knowledge type on search result modality preferences in web search scenarios

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ABSTRACT

Searching information within the web for tasks differing in their knowledge dimension (e.g. conceptual or procedural) is essential for learners in the 21st century. However, little is known about how the underlying knowledge characteristics of learning tasks influence the preference for particular resource modalities (e.g., texts with pictures or videos) the web offers. Across two studies, we investigated how the preference for different resource modalities in hypothetical search scenarios is affected by the knowledge type (sensorimotor procedural, cognitive procedural, causal conceptual, and relational conceptual knowledge). Both studies found an influence of knowledge type on users' modality preferences. A significant preference for videos was found for sensorimotor procedural tasks, while texts with pictures were favoured for cognitive procedural and relational conceptual tasks. For causal conceptional tasks, no differences were found. The observed differences in modality preferences between knowledge types of the same knowledge dimensions (i.e., procedural vs conceptual knowledge) prompted us to investigate in Study 2 an additional knowledge classification, that is, the degree of spatiotemporal changes relevant to the knowledge type. Results showed that knowledge types with a low degree of spatiotemporal changes led to a preference for websites with text and pictures, regardless of their affiliation to procedural or conceptual knowledge. In contrast, videos were preferred only for tasks with a high degree of visuospatial changes and a procedural character. To conclude, the knowledge types and the degree of visuospatial changes of learning tasks seem to be promising classifications to consider regarding modality preferences in models of web-based learning.

1. Introduction

The World Wide Web (hereinafter referred to as "the web") is of ever increasing importance for learning purposes, especially for acquiring or extending one's knowledge about a topic. A standard tool for this purpose is a search engine, such as Google. Users can retrieve all kinds of information by consulting a search engine, including information to help them undertake conceptual learning tasks such as "How does an earthquake occur?" or procedural learning tasks such as "How to tie a double figure-eight knot?". After entering respective search terms, users will be presented with search engine result pages (SERPs) that offer numerous search results. These search results typically lead to a wide range of information. Moreover, the web in general, and search engines in particular, nowadays provide the opportunity to select among different resource modalities such as texts, images, and online videos [1,2]. Search engines integrate these modalities as so-called *universal* or *vertical* search results from specialised search engines, such as image or video searches [3,4,5], into their SERPs. Chen et al. [5] pointed out that the different vertical search results (which generally include multiple different modalities) and their presentation on the SERP affect search satisfaction, search cost, and search benefits. Further, learners' information-seeking behaviour and the search process have become more complex and diverse given the new possibilities of technology and modalities [6]. Metzler et al. [7] predict that future search systems will be able to efficiently and automatically identify and extract information from multiple modalities and combine those into single search results. However, as long as this is not yet the case, learners have to decide which modalities they want to access and in which order.

To date, however, little is known about search engine users' preferences for particular resource modalities, that is, whether they prefer to access text-dominated webpages with or without pictures, pictures only, or videos for their web-based learning. Specifically, so far, to our

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knowledge, there is no research on whether preferences for or against particular modalities interact with the types of knowledge users are searching for.

However, the general idea of using information regarding modality preferences and the knowledge type of a given search intent can be found, for example, in the recent work of Smith et al. [8]. They propose a theoretical framework with different sub-models to capture and analyse learners' web search and learning process in a formal educational context.

Within their framework, they describe the *retrieval model*, which is responsible for preselecting appropriate resources for the learner, including considerations about the characteristics of the task, such as the knowledge type. In addition, the *behaviour model* of the framework monitors the learner's interactions with information resources to predict both information utility and learners' comprehension level. By observing the behaviour of learners, the preference for different modalities on the SERP could be considered to better predict the learners' actions and help refine the *learner assignment model*, which predicts "the knowledge students will learn from the assignment and their possible paths to that knowledge" ([8], p. 193).

In summary, the knowledge type of a task and the preference for a resource modality seem promising but neglected factors to investigate, in order to improve our understanding and predictions of learners' behaviour during web search. For instance, it could help to better understand the actions and needs of learners in formal or informal web-search-based learning settings.

Therefore, in the present paper, we introduce and investigate users' preferences for particular resource modalities and whether those depend on the knowledge type of the learning task they want to undertake with the help of a search engine. This approach follows the suggestion of Urgo et al. [9] to investigate how the knowledge type of tasks influences users' needs and behaviours during web search.

1.1. Selection of information resources during web search

Information resources are usually accessed during web search by clicking on specific search results provided through a search engine. Previous research has focused on different steps [10] and aspects that affect search and specifically selection behaviour during web search. Some of these investigated aspects are the search result rank [11,12], the perceived relevance of the search results for the information task at hand [13,14], credibility cues within search results [15,16], or user-related factors, such as the level of prior knowledge [17] or gender [18].

Also, the influence of the source type of information has been investigated (e.g. [19,20]). Song et al. [20] investigated what source types (professional websites, encyclopedia websites, question and answer websites, news websites, or other websites) Chinese students selected when confronted with health-related receptive or critical tasks. Receptive tasks were defined as being related to the cognitive dimension of understanding, remembering, and being able to reproduce the information (e.g., facts, procedures, or concepts). Critical tasks, in contrast, were defined as being related to the aim that participants could criticise and evaluate a topic from multiple perspectives. Study results showed that the task type did not influence the number of web pages that users selected to complete the task. However, task type significantly impacted the type of resource learners selected. Wiki-type web pages were more often selected and consulted for receptive tasks, while Q&A web pages and news web pages were more often selected and used for critical tasks.

Yet, to our knowledge, the existing literature has neither considered the role of different resource modalities in users' selection decisions nor the potential moderating role of the type of knowledge that users want to acquire. In the following, we will elaborate on the level of knowledge dimensions and underlying knowledge types that can be distinguished in the context of learning tasks.

1.2. Knowledge dimensions and knowledge types

This paper uses the term knowledge dimensions to distinguish between conceptual and procedural knowledge. Additionally, as we will outline in the following, we subdivide each knowledge dimension into two more specific underlying knowledge types based on previous literature (e.g. [21,22,23])

1.2.1. Conceptual knowledge

The first knowledge dimension we introduce is *conceptual knowledge* [21], which is a subdimension of declarative knowledge. The second subdimension of declarative knowledge is factual knowledge, which, however, is not further addressed in the present paper. While factual knowledge deals with single bits of information (e.g., terminology, specific details), which can be found through an easy lookup search [24], conceptual knowledge comprises more complex knowledge about "[…] categories and classifications and relationships between and among them […]" and "[…] includes schemas, mental models, or implicit or explicit theories […]" ([21], p. 48) and therefore often results in exploratory search tasks. Exploratory search tasks are typically more open-ended and need more query iterations [25] than non-exploratory search tasks such as simple lookup searches [24].

However, in our view, conceptual knowledge can be further subdivided into two different knowledge types that share the general attributes of the conceptual knowledge dimension but come with further specifications: causal conceptual knowledge and relational conceptual knowledge.

1.2.1.1. Causal conceptual knowledge. Causal conceptual (CC) knowledge, which is comparable to the definition of "causal tasks" used by van Genuchten et al. [23], addresses knowledge regarding cause-and-effect chains between and within different concepts. Different concepts thereby directly interact and result in an overarching concept. For example, the causal interaction between the formation of clouds and the phenomenon of lightning can be summed up within the resulting concept of thunderstorms.

1.2.1.2. Relational conceptual knowledge. In contrast to causal conceptual knowledge, relational conceptual (RC) knowledge addresses how at least two different concepts relate to each other without describing a direct causality. Our definition of relational conceptual knowledge is comparable to the definition of "conceptual task" used by van Genuchten et al. [23], the definition of "relational categories" by Gentner [26], or what Anderson et al. [21] described as "knowledge of classifications and categories". The latter defined this kind of knowledge as generally more abstract than knowledge of terminology and facts since knowledge about classifications and categories "[…] form the connecting links between and among specific elements" ([21], p. 49). Two concrete examples of relational conceptual knowledge are how rabbits and hares are related to each other, or how direct and alternating electric currents differ.

1.2.2. Procedural knowledge

The second knowledge dimension we introduce is *procedural* *knowledge.* McCormick [27] described procedural knowledge as "know how to do it"- knowledge that encompasses terms like process, problem solving, and strategic thinking of different process levels. According to Corbett and Anderson [28], procedural knowledge consists of knowledge about independent production rules related to different problem states and how to solve them.

Yet, in our view, procedural knowledge can be further subdivided into two types: sensorimotor and cognitive procedural knowledge. Both types have in common that they comprise knowledge on how to perform a self-executable procedure and follow strict orders and rules for necessary sub-steps within the whole procedure but have additional specifications that we will outline in the following.

1.2.2.1. Sensorimotor procedural knowledge. Sensorimotor procedural (SP) knowledge comprises information (including the specific order of steps) needed to conduct a procedural task and is a specification of the general definition of procedural knowledge [21]. The distinguishing characteristic of this subtype of procedural knowledge is the involvement of required motoric movements to acquire the task related to sensorimotor procedural knowledge (cf. [29]). This definition is also strongly related to the definition of knowledge needed to solve "procedural motor tasks" from Garland and Sanchez [22] or "procedural-motor tasks" from Höffler and Leutner [30]. As examples of sensorimotor procedural knowledge, the knowledge about how to tie a specific nautical knot [31] or how to bandage a hand [32] can be listed.

1.2.2.2. Cognitive procedural knowledge. In our definition, cognitive procedural (CP) knowledge comprises all information needed to conduct a procedural task focusing on cognitive operations. In contrast to sensorimotor procedural knowledge, we define that no direct physical or motoric actions are needed to perform the operations, and the process is not directly observable. Our definition of cognitive procedural knowledge can be seen as related to the definition of "procedural knowledge" (e.g., [33]) or "cognitive processes" [34] often used in mathematics. For instance, Carlson and Lundy [34] defined solving mathematical problems as an example of cognitive processes, which have a stepwise and hierarchical goal structure. An example of applying cognitive procedural knowledge would be calculating the resistance within a parallel circuit.

1.3. Previous research on the role of the knowledge dimension within web search

Only a few studies have considered the role of knowledge dimensions in processes of information seeking on the web. Worth mentioning is the work of Eickhoff and colleagues, in which they argue that search sessions "[…] can be divided into procedural and declarative sessions, both of which show significant differences from sessions without explicit knowledge acquisition intent as well as from each other." ([35], p. 231). They found, for example, that, in search sessions looking for procedural knowledge, learners tended to increase the average time spent reading retrieved documents towards the end of a search session. Furthermore, Eickhoff and colleagues automatically derived cue words within search queries that indicated whether learners were searching for procedural or declarative knowledge. Cue words for procedural knowledge were, for example, "how to" or "how do I", while for declarative searches, terms like "what is" or "who" were used. However, they did not specifically examine search result selection or the use of different resource modalities as a function of the procedural or declarative knowledge dimension.

Another example of considering the knowledge dimension in the context of web search is the work of Urgo et al. [36]. They investigated how the knowledge dimension (factual, conceptual, procedural) of learning tasks influenced the search behaviour of learners. First, they found that participants did indeed perceive a greater need for facts during factual knowledge tasks, a greater need for concepts during conceptual knowledge tasks, and a greater need for procedures during procedural knowledge tasks. Further, factual knowledge tasks were perceived to involve lower levels of cognitive activity than the other two task types. Conceptual knowledge tasks were perceived to involve more “understanding” and “analysing” while procedural knowledge tasks were perceived to involve more “applying”, “evaluating”, and “creating” than the two other task types. Finally, conceptual knowledge tasks were perceived as more complex than procedural knowledge tasks. Regarding the search behaviour, participants entered more queries for conceptual knowledge tasks than for procedural and factual knowledge tasks and took longer task completion times for conceptual tasks. Even though participants could choose among general web search results, image search results, news search results, and video search results provided in four different tabs, Urgo et al. [36], did not investigate the influence of the knowledge dimension on the selection of different resource modalities.

A recent survey study by Choi et al. [37] investigated intelligence analysts’ needs, practices, and challenges while searching for procedural knowledge within an internal information system. They used the cognitive process dimensions (understand, apply, analyse, evaluate, and create) to categorise work tasks related to the procedural knowledge the analysts searched for. However, the study focused exclusively on procedural knowledge without considering other knowledge dimensions or the use of different resource modalities. To conclude, to our knowledge, no previous research has investigated the preference for different resource modalities during a web search, especially under consideration of different knowledge types of the tasks.

1.4. The present research

The main goal of the research presented here was to investigate whether and to which degree the knowledge type of a learning task that users aim to accomplish with the help of a search engine potentially moderates their preference for particular resource modalities (e.g., texts or videos). Specifically, we report the results of two experimental studies: first, an exploratory study (Study 1) and second, a pre-registered study (Study 2). In both studies, we used the classification of knowledge types introduced above to analyse the resource modality preferences of university students confronted with hypothetical web-based learning scenarios. As operationalisation for preference, in Study 1, we measured the ranking of resource modalities and, in Study 2, the extent of intended usage of resource modalities.

Study 1 served as a first approach to investigate our general research question, whether the knowledge type (sensorimotor procedural, cognitive procedural, causal conceptual, and relational conceptual knowledge) moderates users’ preferences for different modalities of information resources (texts without pictures, texts with pictures, pictures, and videos).

In Study 2, we took the findings of Study 1 into account to test specific hypotheses regarding the moderating effects of knowledge type on the preference for different resource modalities, or more precisely, on the extent of intended usage of these resource modalities.

2. Study 1

2.1. Method

2.1.1. Research model and procedure

The study used a 4 × 4 factorial within-subjects design with the factors knowledge type (sensorimotor procedural, cognitive procedural, causal conceptual, and relational conceptual) and resource modality (texts without pictures, texts with pictures, pictures, and videos). All items were presented in a randomised order without participants’ knowing the assigned knowledge type of the presented item.

The study consisted of an online session and a lab session. In the online questionnaire, which was filled out on average 3.41 days (*SD* = 1.45 days, *min* = 1, *max* = 10 days) before the lab session, participants were asked to provide demographics and to self-assess their prior knowledge on a 7-point scale from 1 = "no knowledge at all" to 7 = "very good knowledge" for the 20 different topics of the search tasks. In the lab session, participants were tested in group sessions (of up to 6). In the beginning, participants gave their informed consent and were seated in front of a laptop where they worked on the study within the online survey tool Qualtrics. Participants were then informed that they would be confronted with 20 different learning-related search tasks and that the objective for each task would be to imagine using a search engine to search enough information to successfully accomplish the task at hand, for example, in a test. Beyond that, they were informed that they would have to indicate the preferred modality they would select to learn about the task. Then, participants were confronted with the 20 tasks in randomised order. Each task was presented on a single page where participants had to indicate their preference regarding the resource modality (texts without pictures, texts with pictures, pictures, and videos) for the hypothetical web search, by rank-ordering the four options for each task. Participants did not have to conduct a web search or learn about the topic.

2.1.2. Sample

Participants were recruited via a local, web-based online recruitment system of a large German university and reimbursed with 6€ per person. After 14 dropouts between the online and laboratory phase of the study, the final sample consisted of 61 undergraduate students (77.05% female, $M = 24.51$ years old, $SD = 3.23$) from different majors (23 students were from humanities, e.g., language studies, 16 were from natural sciences, e.g., physics or medicine, and 22 were from social sciences, e.g. educational science).

2.1.3. Instruments used

Participants were confronted with 20 learning-related search tasks (5 tasks per knowledge type) and asked to indicate their preferred resource modality (texts without pictures, texts with pictures, pictures, videos) to learn about each task. The topics of the tasks originated from different fields, namely: mathematics, physics, biology, and technology. Participants were asked to imagine that they would have to learn about the task at hand with the help of a search engine (e.g., Google) and the internet. Each task was presented with the initial sentence: "Imagine that you should learn with the help of the Internet and a search engine … " followed by the learning task (see Table 1). For each task, participants were asked to rank the four modalities according to their preference of using them to learn about the topic. Therefore, they assigned the preference rank from 1 = "first choice" to 4 = "last choice" to the four modalities. The sequence (text without pictures, text with pictures, pictures, videos) in which the rank for modalities had to be indicated was kept identical for all 20 tasks. Each rank could be assigned only once.

2.1.4. Data analysis

As the dependent variable, we calculated the mean preference rank (see Table 2) for each of the four modalities (texts without pictures, texts with pictures, pictures, and videos) for each of the four knowledge types per participant, by averaging the assigned ranks chosen for the five tasks within each knowledge type (sensorimotor procedural, causal conceptual, cognitive procedural, and relational conceptual).

To investigate our research question as to whether the underlying knowledge type moderated the preference for the specific resource modalities, we calculated a 4 × 4 repeated measures ANOVA. The factors knowledge type and resource modality served as within-subject factors and the mean preference rank (averaged across five tasks) as the dependent variable. Due to the exploratory approach of analysing our research questions, the Bonferroni correction method for multiple testing [38] was used to account for alpha error accumulation. The effect size (d_{av}) was calculated based on the approach for repeated-measures designs described by Lakens [39], using averaged standard deviations of comparisons.

Based on the ranking approach, that is, assigning per task one of four ranks to a modality, no main effect for knowledge type could occur in this study. This was a result of the fact that the indication of ranking within a closed ranking system (1 to 4) did not allow any variance within the knowledge type, since the overall mean for the rank score was always $M = 2.5$ when the interaction with modality was not taken into account. However, since our research question aimed at investigating the interaction between resource modality and knowledge type, a statistically valid analysis was still possible.

Table 1
Learning tasks presented to participants per knowledge type.

Knowledge type	Item No.	Item
Sensorimotor procedural (SP)	SP1	how to draw a pentagon with the help of a compass
	SP2	how to tie a double figure-eight knot
	SP3	how to apply a pressure bandage to the hand
	SP4	how to replace the display of the iPhone X
	SP5	how to jump-start a car with a flat battery
Cognitive procedural (CP)	CP1	how to calculate the electrical resistance in a parallel circuit
	CP2	how to calculate the volume of a prism
	CP3	how to calculate the probability in an urn problem with replacement
	CP4	how to calculate the magnetic field strength of a cylindrical coil
	CP5	Study 1: how to program a while loop in Python Study 2: how to calculate compound interest
Causal conceptual (CC)	CC1	how a drum brake works
	CC2	how thunderstorms form
	CC3	how an earthquake occurs
	CC4	how a wind turbine works
	CC5	how a camera obscura works
Relational conceptual (RC)	RC1	what the relationship is between voltage and the number of turns in a transformer
	RC2	how weather and climate are related
	RC3	how pulse and blood pressure are related
	RC4	what the relationship is between rabbits and hares
	RC5	how alternating current and direct current differ

Note. The tasks were presented to the participants in random order.

Table 2
Mean preference rank (with SD) for the four modalities as a function of knowledge type.

Modality	Procedural				Conceptual			
	Sensorimotor (SP)		Cognitive (CP)		Causal (CC)		Relational (RC)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Pictures	2.78	0.42	3.35	0.57	3.27	0.58	3.42	0.56
Texts without Pictures	3.71	0.48	2.72	0.73	3.24	0.64	2.56	0.71
Texts with Pictures	2.13	0.44	1.58	0.47	1.70	0.53	1.62	0.50
Videos	1.38	0.56	2.36	0.75	1.80	0.75	2.40	0.72

2.2. Results

Participants' self-reported prior knowledge for the tasks did not significantly differ across knowledge types, $F(3, 240) = 2.03$, $p = .110$. Generally, the reported prior knowledge was low to medium for the different knowledge tasks ($M = 2.56$, $SD = 0.85$).

Regarding our research question as to whether there was a significant interaction between modality and knowledge type, the repeated-measures ANOVA revealed a significant interaction between knowledge type and resource modality, $F(9, 540) = 54.07$, $p < .001$, $\eta_p^2 = .47$.

2.2.1. Comparisons of the mean preference ranks between resource modalities within knowledge types

To further explore the significant interaction between modality and knowledge type, we calculated Bonferroni corrected post hoc tests to investigate the differences within each knowledge type (see Fig. 1).

For sensorimotor procedural (SP) knowledge tasks, significant differences among the preference ranks of all four modalities were found (all $p < .001$). Videos were the top ranked modality ($M = 1.38$, $SD = 0.56$), followed by texts with pictures ($M = 2.13$, $SD = 0.44$), pictures ($M = 2.78$, $SD = 0.42$), and lastly texts without pictures ($M = 3.71$, $SD = 0.48$). Again, it is important to clarify that a higher preference rank equalled a lower modality preference, since preference was indicated in descending order from 1 = "first choice" to 4 = "last choice".

For the cognitive procedural (CP) knowledge tasks, the most favoured modality was texts with pictures ($M = 1.58$, $SD = 0.47$), which differed significantly from all other modalities (all $p < .001$). In contrast, the mean preference rank for videos ($M = 2.36$, $SD = 0.75$) and for texts without pictures ($M = 2.72$, $SD = 0.73$) did not significantly differ ($p = .411$). The mean preference rank for pictures ($M = 3.35$, $SD = 0.57$) was significantly higher (i.e., pictures were less preferred) than the mean preference rank for all other modalities (all $p < .002$).

For the relational conceptual (RC) knowledge tasks, again texts with pictures ($M = 1.62$, $SD = 0.50$) were shown to be the most favoured modality (all $p < .001$). Again, the mean preference rank for videos ($M = 2.40$, $SD = 0.72$) and texts without pictures ($M = 2.56$, $SD = 0.71$) did not differ significantly ($p > .999$). The mean preference rank for pictures ($M = 3.42$, $SD = 0.56$) again was significantly higher (i.e., pictures were

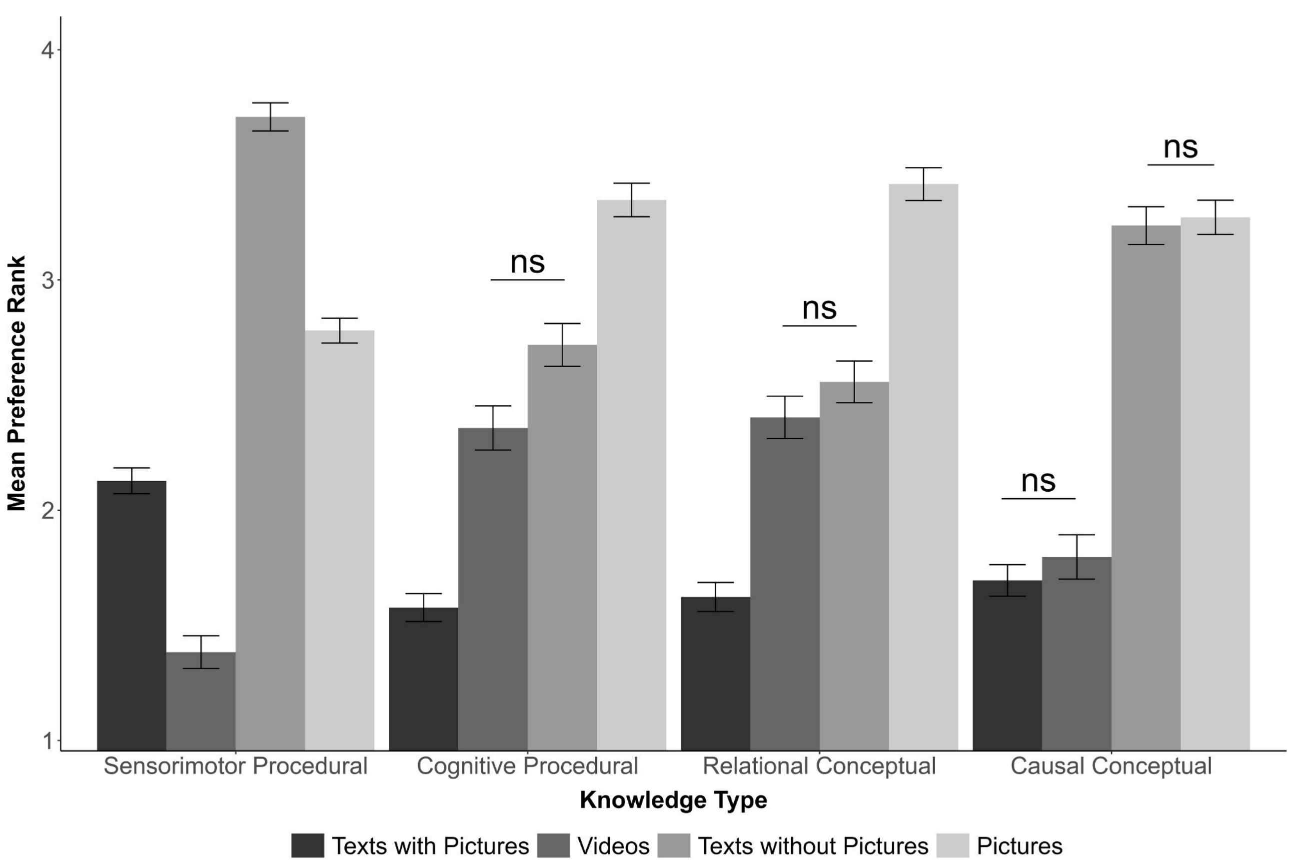

Fig. 1. Mean preference rank for the four modalities as a function of knowledge type.
Note: All comparisons within the knowledge types that are not marked as not significant reached a significant level. Error bars represent standard errors. ns: not significant.

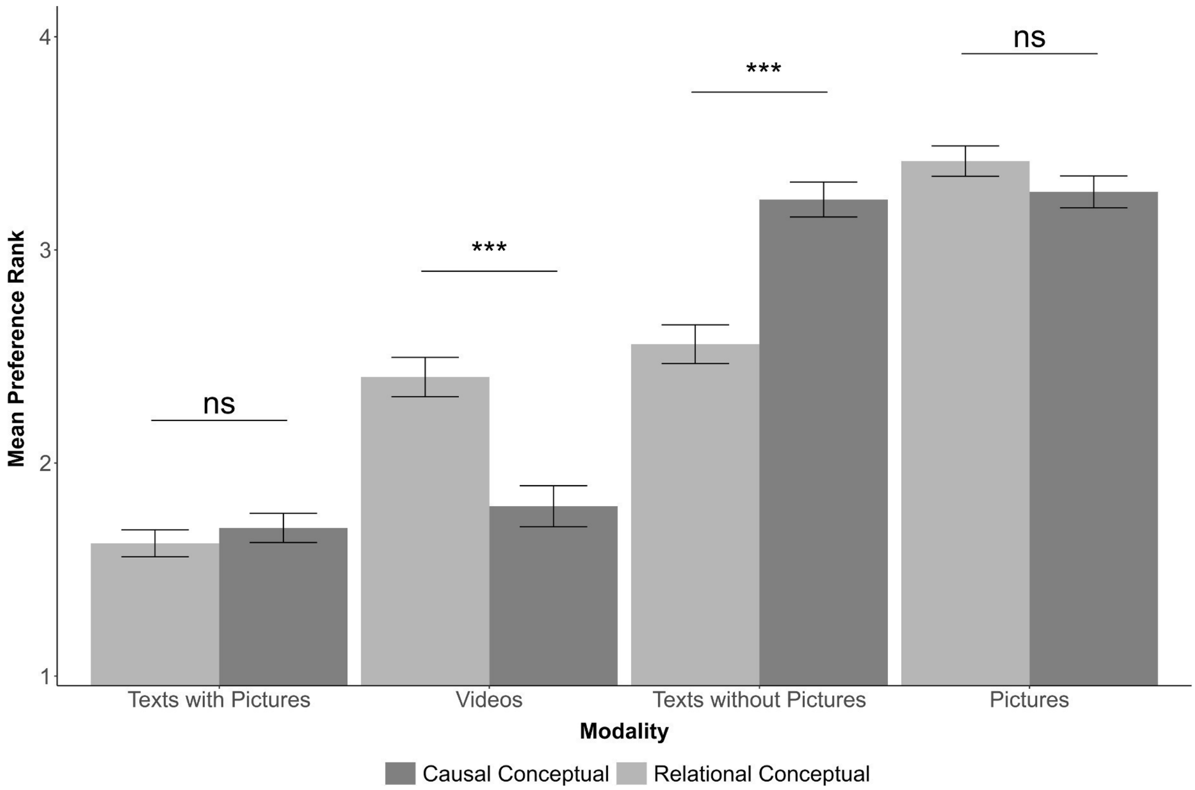

Fig. 2. Comparisons of the mean preference ranks of the four modalities between CC and RC tasks.
Note: Error bars represent standard errors. ns: not significant, ***: $p < .001$.

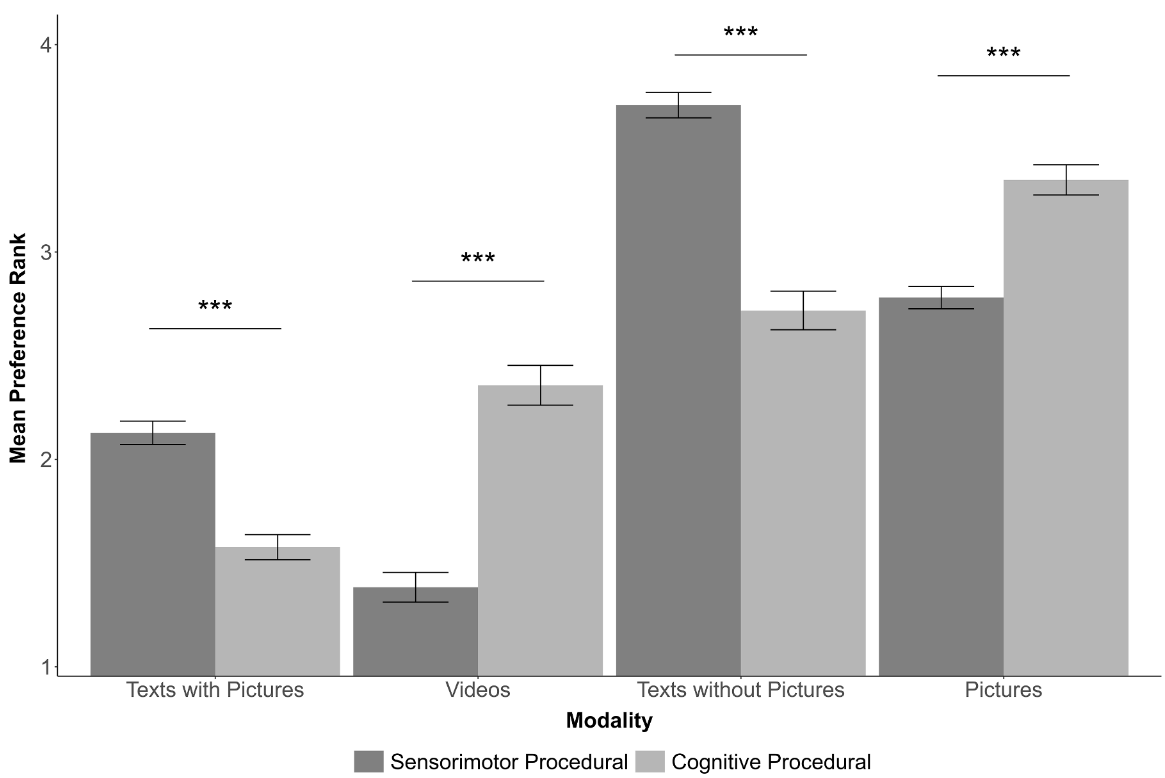

Fig. 3. Comparisons of the mean preference ranks of the four modalities between SP and CP tasks.
Note: Error bars represent standard errors. ***: $p < .001$.

less preferred) than the mean preference rank for all other modalities (all $p < .001$).

For the causal conceptual (CC) knowledge tasks, the mean preference rank for both texts with pictures ($M = 1.70$, SD = 0.53) and videos ($M = 1.80$, $SD = 0.75$) was significantly lower, that is, texts with pictures and videos were more preferred (all $p < .001$), than the mean preference rank for pictures ($M = 3.27$, $SD = 0.58$) and for texts without pictures ($M = 3.24$, $SD = 0.64$). The mean preference rank for texts with pictures and for videos did not differ significantly ($p > .999$), nor did the mean preference rank for pictures and texts without pictures ($p > .999$).

2.2.2. Comparisons of the mean preference ranks between knowledge types of the same dimension

Since there were differences between knowledge types even if they belonged to the same knowledge dimension (i.e., procedural knowledge or conceptual knowledge, respectively), we further calculated Bonferroni corrected post hoc tests to investigate differences in the mean preference ranks of the four modalities between CC tasks and RC tasks (both classified as belonging to the conceptual knowledge dimension) and between SP tasks and CP tasks (both classified as belonging to the procedural knowledge dimension), respectively.

Within the conceptual knowledge dimension (see Fig. 2), the mean preference rank for videos was significantly lower (i.e., videos were more preferred) for CC tasks than for RC tasks, $t(600) = -7.60$, $p < .001$, $d_{av} = 0.82$. In contrast, the mean preference rank for texts without pictures was significantly higher (i.e., texts without pictures were less preferred) for CC tasks than for RC tasks, $t(600) = 8.49$, $p < .001$, $d_{av} = 1.02$. The mean preference ranks of the two other modalities did not differ between CC tasks and RC tasks (all $p > .999$).

Within the procedural knowledge dimension (see Fig. 3), the mean preference ranks for videos, $t(600) = -12.19$, $p < .001$, $d_{av} = 1.50$, and pictures, $t(600) = -7.10$, $p < .001$, $d_{av} = 1.15$, were significantly lower (i.e., videos and pictures were more preferred) for SP tasks than for CP tasks. In contrast, the mean preference ranks for texts with pictures, $t(600) = 6.89$, $p < .001$, $d_{av} = 1.21$, and texts without pictures, $t(600) = 12.39$, $p < .001$, $d_{av} = 1.34$, were significantly higher (i.e., texts with or without pictures were less preferred) for SP tasks than for CP tasks.

2.3. Discussion of Study 1

Study 1 showed that texts with pictures and videos were the two most favoured modalities across all knowledge types, whereas pictures and texts without pictures were less favoured. However, the results further indicated that participants' preferences for particular resource modalities were moderated by the knowledge type of the underlying learning task, which means that our research question can be answered in the affirmative. For the sensorimotor procedural (SP) tasks, significant differences between the preference ranks of all four modalities were found, with videos being the top-ranked modality. On the contrary, for both the cognitive procedural (CP) and the relational conceptual (RC) tasks, the most favoured modality was texts with pictures, which differed significantly from all other modalities. Finally, for the causal conceptual (CC) tasks, both texts with pictures and videos were the most favoured modalities. To conclude, different results pattern were found for knowledge types belonging to the same knowledge dimension (i.e., to the knowledge dimension of procedural knowledge or the knowledge dimension of conceptual knowledge, respectively).

In contrast, similar results patterns were found for the tasks belonging to cognitive procedural (CP) knowledge and relational conceptual (RC) knowledge (see Fig. 1). In both cases results showed a clear advantage for texts with pictures. Videos and text without pictures were rated as second choice in both knowledge types. Also, similar results patterns were found for the tasks belonging to sensorimotor procedural (SP) knowledge and causal conceptional (CC) knowledge. In both cases, videos and text with pictures were preferred over pictures and text without pictures. These results were somewhat unexpected, since knowledge types of the same knowledge dimension share similar characteristics and structures of knowledge. Thus, in Study 2 we aimed to conceptually replicate these patterns of results.

3. Study 2

Since the modalities of pictures and texts without pictures played a negligible role in users' preferences in Study 1, we decided to drop these two modalities for Study 2. Further, we reframed the two remaining modalities of texts with pictures and videos into websites with text and pictures and online-videos, respectively, to approximate the modalities to a natural web search. Also, instead of asking for a ranking of the different modalities as in Study 1, participants in Study 2 were asked to indicate the hypothetical extent of using each of the two modalities separately on a scale from 1 = "not at all" to 7 = "very".

Our general hypothesis was that the extent of intended usage of websites with text and pictures and of videos would depend on the knowledge type of a learning task (H1). Based on the results from Study 1, we formulated concrete pre-registered hypotheses regarding the extent of intended usage of websites with text and pictures, on the one hand, and online-videos, on the other hand, for the four knowledge types. Our hypotheses are as follows:

- H1.1: For sensorimotor procedural (SP) tasks, participants will indicate using online-videos significantly more than websites with text and pictures.
- H1.2: For cognitive procedural (CP) tasks, participants will indicate using websites with text and pictures significantly more than online-videos.
- H1.3: For relational conceptual (RC) tasks, participants will indicate using websites with text and pictures significantly more than online-videos.
- H1.4: For causal conceptual (CC) tasks, there will be no differences between resource modalities.

3.1. Method

3.1.1. Research model and procedure

The study used a 4 × 2 factorial within-subjects design with the factors knowledge type (sensorimotor procedural, cognitive procedural, causal conceptual, and relational conceptual knowledge) and resource modality (websites with text and pictures, online-videos). All items were presented in a randomised order without participants knowing the assigned knowledge type of the presented item. Half of the participants (random assignment) had to rate the extent of intended usage of videos first and the extent of the intended usage of websites second in all 20 learning tasks. For the other half of the participants, the sequence was reversed. Again, participants were asked for their hypothetical preference without performing a web search.

The learning scenario and the 20 learning tasks were identical to those in Study 1, except for one task. One task belonging to the cognitive procedural dimension (CP 5, "how to program a while-loop with the programming language Python") was replaced by the task "how to calculate compound interest". This task was replaced due to its poor psychometric fit with the other tasks within the knowledge type.

3.1.2. Sample

After 11 dropouts between the online and laboratory phase, the final sample of Study 2 consisted of 65 undergraduate students (78.46% female, $M = 23.89$ years old, $SD = 2.95$) from different majors (33 from social sciences, 20 from natural sciences, and 12 from humanities) at a large German university. Students who had already participated in Study 1 were excluded from Study 2. Participants were reimbursed with 10€. The number of needed participants was determined through a power analysis conducted with G*Power [40] for an "ANOVA: Repeated measures, within factors" with the following, assumed values: Effect size $f = 0.25$; α err prob =.5 According to the calculation of G*Power, a power of 0.83 was already reached with a total sample size of 56.

3.1.3. Data analysis

As the dependent variable, the extent of the intended usage of each of the two modalities (websites with text and pictures or online-videos) was assessed separately for each modality on a scale from 1 = "not at all" to 7 = "very much" ("How much would you use websites with text and pictures / online videos in order to learn about the topic?"). The extent of intended usage for the two modalities was calculated for each knowledge type by averaging the reported extent of usage across the five tasks of each knowledge type, with higher scores indicating a greater extent of intended usage. The rating scales for both resource modalities were presented on the same page, below the description of the learning task. As in Study 1, the 20 learning tasks were presented in randomised order, and participants worked on the tasks in a self-paced manner without any time limit.

Based on Study 1, to test our general hypothesis (H1) on whether the underlying knowledge type moderated the extent of intended usage of the two resource modalities, we calculated a 4 × 2 repeated measures ANOVA. Knowledge type and resource modality served as within-subject factors and the extent of intended usage (averaged across the five tasks) served as the dependent variable. For the within-subject factor of knowledge type, the four levels remained the same as in Study 1. For this analysis, we pre-registered Bonferroni corrected [38] post hoc analyses differentiating the extent of intended usage for modalities within each knowledge type.

3.2. Results

As in Study 2, participants' self-reported prior knowledge for the tasks did not significantly differ across knowledge types, $F(3, 256) = 0.71$, $p = .546$. Generally, indicated prior knowledge was low to medium for all knowledge types ($M = 2.80$, $SD = 0.93$).

3.2.1. Comparisons of the extent of intended usage between resource modalities within knowledge types

The repeated-measures ANOVA revealed a significant main effect for knowledge type, $F(3,192) = 5.66$, $p < .001$, $\eta_p^2 = .04$, while the main effect of modality was not significant, $F(1,64) = 0.37$, $p = .545$, $\eta_p^2 = .01$. As expected in H1, a significant interaction effect between knowledge type and modality was found, $F(3,192) = 130.00$, $p < .001$, $\eta_p^2 = .67$. To investigate the differences between resource modalities within knowledge types, as pre-registered within the hypotheses, we used Bonferroni corrected planned contrasts (also see Fig. 4).

In line with H1.1, for the sensorimotor procedural (SP) tasks, participants indicated a significantly lower extent of intended usage of websites with text and pictures ($M = 4.19$, $SD = 1.16$), than of online-videos ($M = 6.53$, $SD = 0.64$), $t(172) = -12.80$, $p < .001$, $d_{av} = 2.6$. Also, in line with H1.2, for the cognitive procedural (CP) tasks, participants indicated a significantly higher extent of intended usage of websites with text and pictures ($M = 5.94$, $SD = 0.94$) than of online-videos ($M = 4.60$, $SD = 1.39$), $t(172) = 7.35$, $p < .001$, $d_{av} = 1.15$.

Furthermore, in line with H1.3, for the relational conceptual (RC) tasks, a significant advantage for websites with text and pictures ($M = 5.89$, $SD = 0.80$) over online-videos ($M = 4.76$, $SD = 1.21$) was found, $t(172) = 6.19$, $p < .001$, $d_{av} = 1.12$. Finally, for the causal conceptual (CC) tasks, in line with H1.4, no significant difference between the extent of intended usage of websites with text and pictures ($M = 5.32$, $SD = 0.90$) and online-videos ($M = 5.79$, $SD = 0.81$) was found, $t(172) = -2.58$, $p = .299$.

3.2.2. Comparisons of the extent of intended usage of resource modalities between knowledge types of the same knowledge dimension

As in Study 1, knowledge types belonging to the same knowledge dimension showed differences for the preferred resource modalities. We therefore further calculated Bonferroni corrected post hoc tests to investigate the differences in the extent of intended usage of the two modalities between CC tasks and RC tasks (both classified as conceptual knowledge dimension) and between SP tasks and CP tasks (both classified as procedural knowledge dimension), respectively.

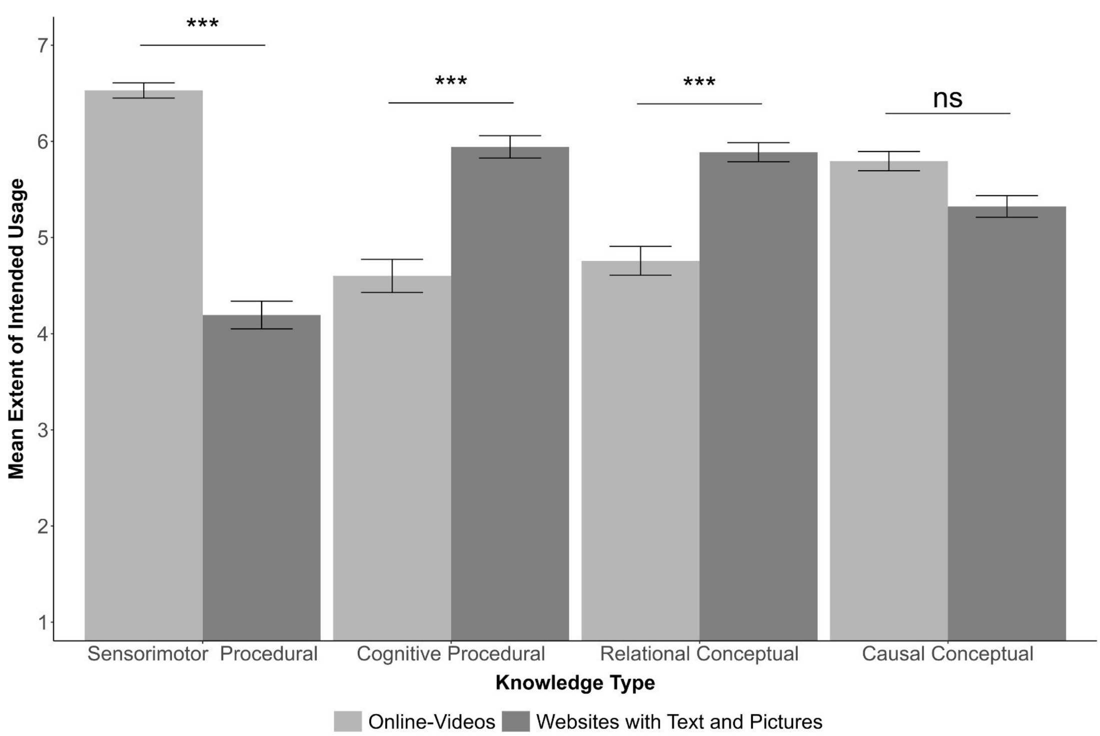

Fig. 4. Mean extent of intended usage of the two modalities as a function of knowledge types.
Note: Error bars represent standard errors. ns: not significant, ***: p < .001.

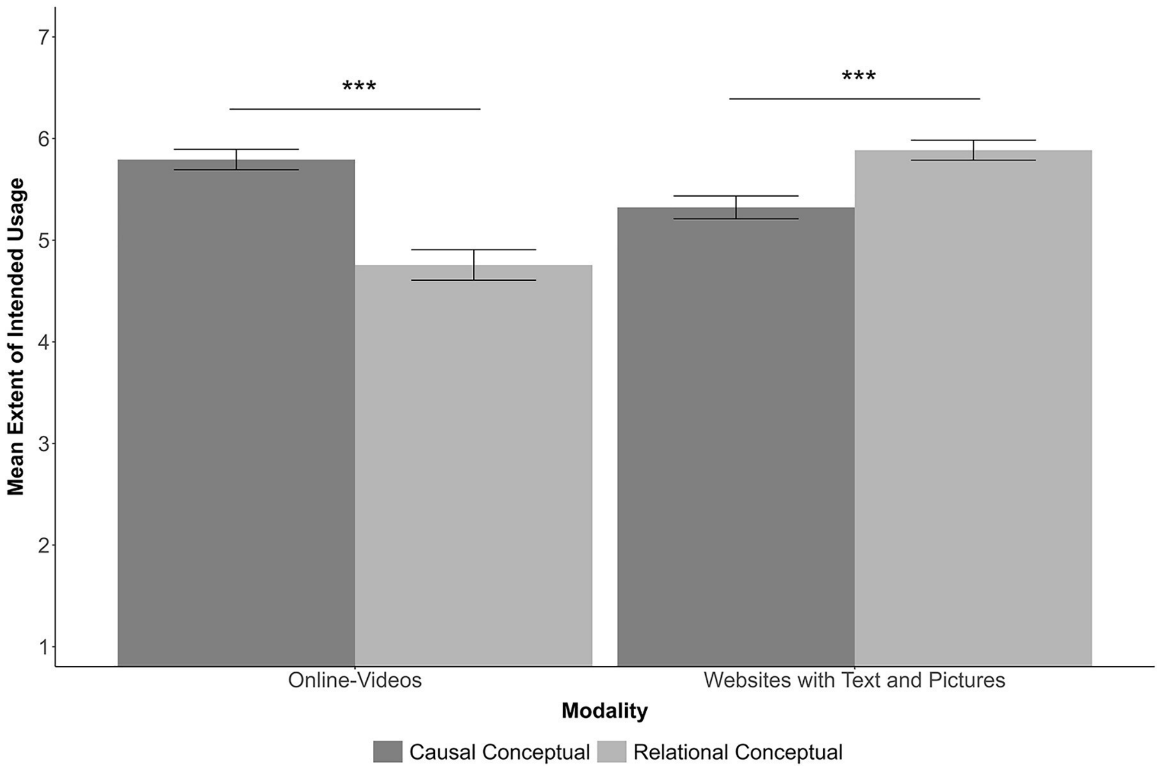

Fig. 5. Mean extent of usage as a function of modality for conceptual knowledge dimensions.
Note: Error bars represent standard errors. ns: not significant, ***: p < .001.

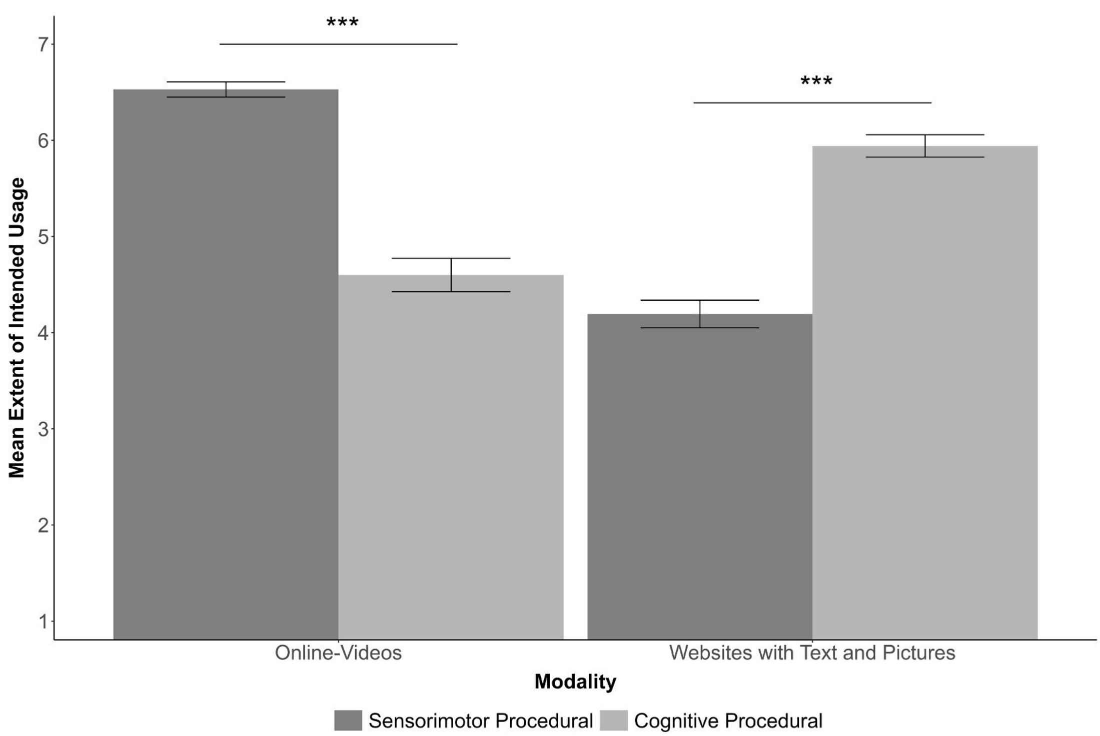

Fig. 6. Mean extent of usage as a function of modality for procedural knowledge dimensions.
Note: Error bars represent standard errors. ***: p < .001.

Within the conceptual knowledge dimension (see Fig. 5), the mean extent of intended usage of online-video was significantly higher for CC tasks than for RC tasks, $t(320) = 7.69$, $p < .001$, $d_{av} = 1.02$. In contrast, the mean extent of intended usage of websites with text and pictures was significantly lower for CC tasks than for RC tasks, $t(320) =$ -4.18, $p =$ .001, $d_{av} = 0.67$.

Within the procedural knowledge dimension (see Fig. 6), the mean extent of intended usage of online-videos was significantly higher for SP tasks than for CP tasks, $t(320) = 14.31$, $p < .001$, $d_{av} = 1.90$. In contrast, the mean extent of intended usage for websites with text and pictures was significantly lower for SP tasks than for CP tasks, $t(320) = -12.96$, $p < .001$, $d_{av} = 1.67$.

3.3. Discussion of Study 2 and exploratory analyses

Study 2 replicated the finding that the knowledge type moderates the preference for different resource modalities. All directed hypotheses for the four knowledge types were supported, and therefore, the preference patterns for the single knowledge types were replicated.

For sensorimotor procedural (SP) tasks, videos were the most favoured modality, while for cognitive procedural (CP) and relational conceptual (RC) tasks, the most favoured modality was websites with text and pictures. No clear preference was found for the causal conceptual (CC) tasks. The following section will interpret the results and describe exploratory analyses based on the observed patterns.

3.3.1. Interpretation of the obtained results patterns

We observed that the pairs of knowledge types for procedural knowledge and conceptual knowledge, respectively, showed nonuniform patterns (e.g., while websites with text and pictures were favoured for CP tasks, videos were favoured for SP tasks). Thus, the results indicate that the differences in modality preferences between knowledge types do not seem to be affected by the knowledge dimension of a task but rather by another characteristic underlying the learning tasks.

Based on the research of Ploetzner et al. [41], we identified that this characteristic might be the degree to which the display of spatiotemporal changes is relevant to the knowledge type for learning. Ploetzner and colleagues considered that "[…] the displayed changes and how they unfold in time are relevant to learning […]" ([41], p. 853) and found that this factor influences learning efficiency with different modalities. Spatiotemporal changes generally comprise visual or depictable changes in shape, size, location, direction, or speed [42]. Taking this into account, we investigated the possibility of distinguishing the degree of spatiotemporal changes within our used knowledge types. As we will argue in the following, knowledge types of the same knowledge dimension (i.e., procedural or conceptual knowledge) can differ in their degree of spatiotemporal changes.

For example, within the procedural knowledge dimension, the degree of spatiotemporal changes in the sensorimotor procedural (SP) tasks can be defined as high, since performing sensorimotor movements are necessary to complete the task. These movements are observable and result in changes of relations between entities (e.g., location, direction), that is, spatiotemporal changes. In contrast, the processing steps necessary to solve cognitive procedural (CP) tasks are not directly observable. It is possible to externalise sub-steps visually, such as a part of a calculation in the form of numbers. However, this is just an abstract visualisation of results and not the execution of a process resulting in perceivable spatiotemporal changes. Hence, we argue that the degree of displayed visuospatial changes is low for CP tasks.

The same differentiation can be applied to the conceptual knowledge dimension and its types. For causal conceptual (CC) tasks, causalities naturally lead to changes of properties (e.g., size or colour) or changes between entities (e.g., location, distance, speed) which can be displayed through spatiotemporal changes. Hence, we argue that the degree of displayed visuospatial changes is high for the CC tasks. In contrast, for relational conceptual (RC) tasks, visual representations of concepts can only be depicted mostly in static pictures due to the absence of spatiotemporal changes. Other than for CC tasks, no changes of properties or entities are perceivable over time. Therefore, we argue that the degree of displayed spatiotemporal changes is low for the RC tasks.

Based on these considerations, we defined the degree of spatiotemporal changes in SP tasks and CC tasks as high, while for CP and RC tasks the degree was defined as low. Accordingly, in order to explore our new assumption that the degree of spatiotemporal changes within knowledge types moderates the modality preference, we devised a statistical model in which the four knowledge types were represented by a 2 × 2 design

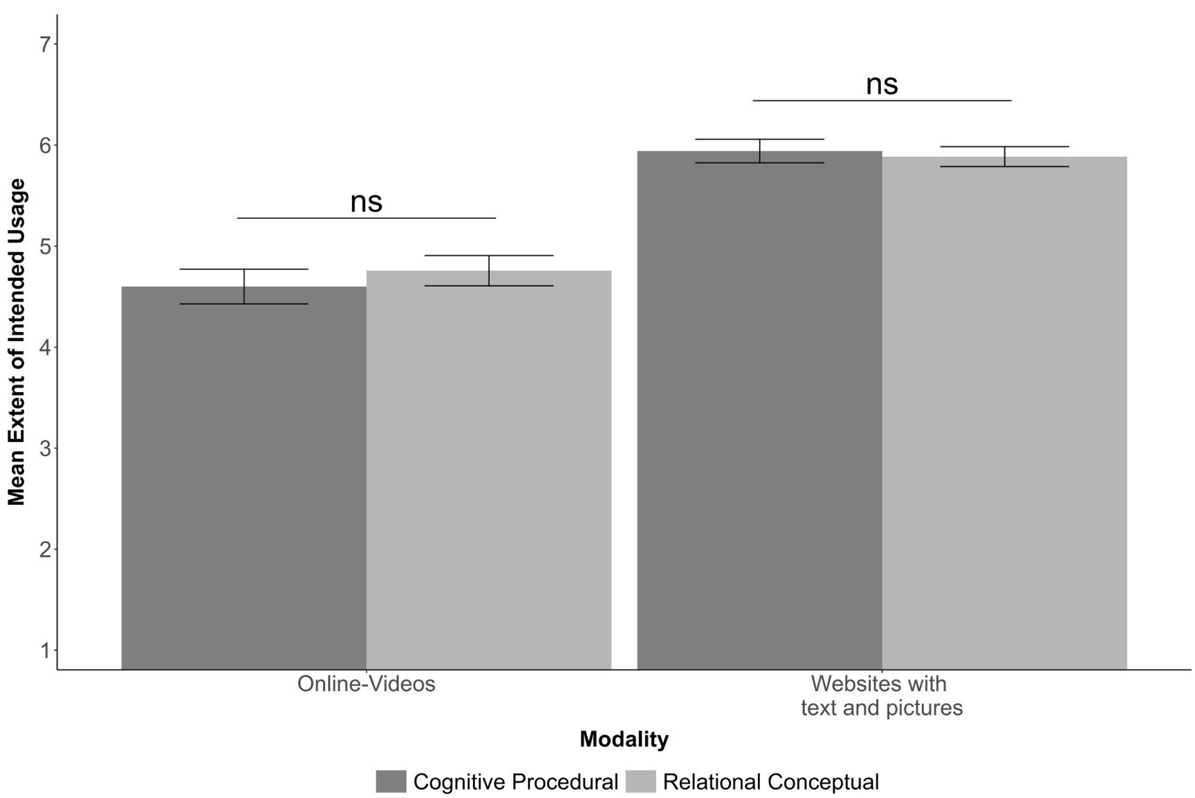

Fig. 7. Mean extent of intended usage of the two resource modalities for the two knowledge types with a low degree of spatiotemporal changes.
Note: Error bars represent standard errors. ns: not significant.

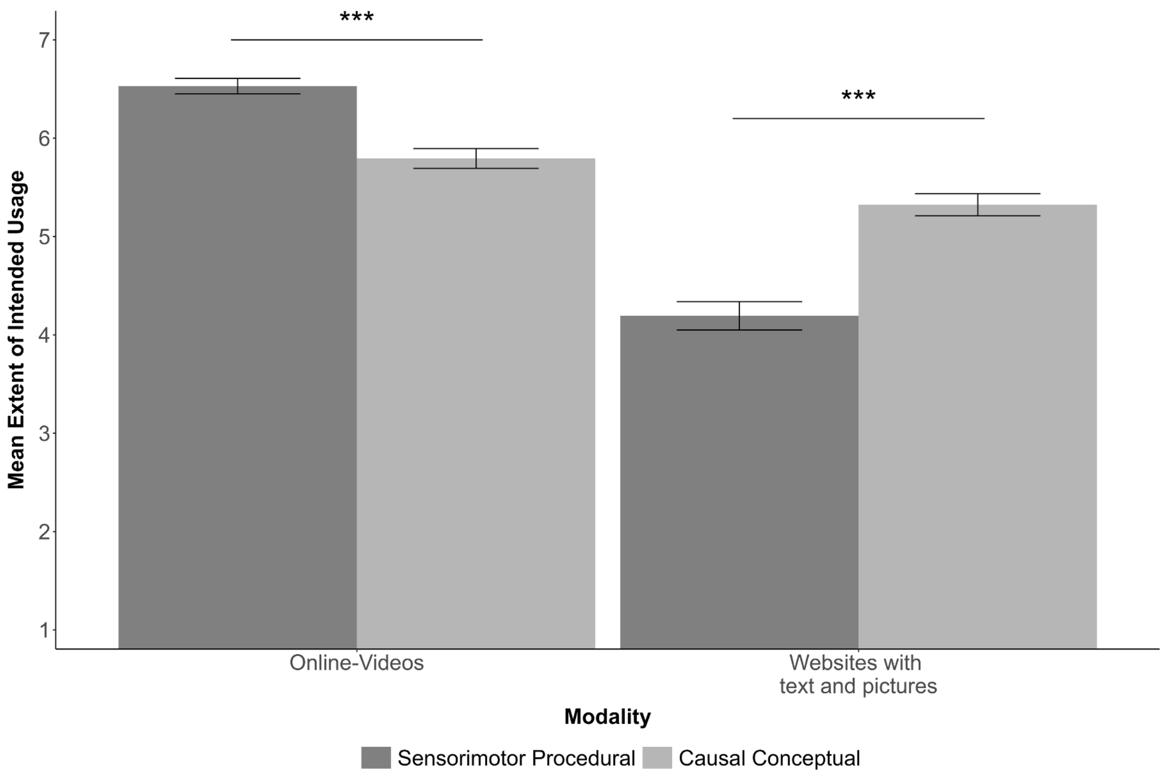

Fig. 8. Mean extent of intended usage of the two resource modalities for the two knowledge types with a high degree of spatiotemporal changes.
Note: Error bars represent standard errors.
*** p < .001.

with the factors knowledge dimension (conceptual, procedural) and degree of spatiotemporal changes (low, high). This resulted in a 2 (conceptual, procedural) x 2 (low, high degree of spatiotemporal changes) x 2 (online-videos, websites with text and pictures) factorial repeated measures ANOVA.

3.3.2. *Additional exploratory results*

Our exploratory repeated-measures ANOVA with the new factor revealed a significant three-way interaction among knowledge dimension, degree of spatiotemporal changes, and resource modality, $F(1, 256) = 56.71$, $p < .001$, $\eta_p^2 = .18$. This supports our assumption that, beyond general classification into knowledge dimensions, the factor of spatiotemporal changes could moderate the preference for modalities. In order to examine the results further, we calculated contrasts for the knowledge types with a high and low degree of spatiotemporal changes.

An identical results pattern was found for knowledge types showing a low degree of spatiotemporal changes (CP, RC). That is, no significant differences (both $p > .999$) between CP and RC tasks in the extent of intended usage of videos or websites with text and pictures could be found (see Fig. 7). As reported in section 3.2.1, for both knowledge types, the extent of intended usage for websites with text and pictures was significantly higher (both $p < .001$) than for online-videos.

For the two knowledge types with a high degree of spatiotemporal changes (SP, CC), the extent of intended usage of online-videos was higher than for websites with text and pictures (see Fig. 8). As reported in section 3.2.1, however, the advantage of online-videos over websites with text and pictures did not reach significance for causal conceptual (CC) tasks. Furthermore, the difference in the extent of intended usage of online-videos between the SP and CC knowledge types reached significance, $t(312) = -5.73$, $p < .001$, $d_{av} = 1.01$. The extent of intended usage of online-videos was significantly lower for conceptual tasks with a high degree of spatiotemporal changes (CC tasks) than for procedural tasks with a high degree of spatiotemporal changes (SP tasks). At the same time, the extent of intended usage of websites with text and pictures was significantly higher for conceptual tasks with a high degree of spatiotemporal changes (CC tasks), $t(312) = 8.79$, $p < .001$, $d_{av} = 1.10$, than for procedural tasks with a high degree of spatiotemporal changes (SP tasks).

To summarise, our exploratory analyses revealed that for knowledge types that we identified as having a low degree of spatiotemporal changes (RC and CC), (a) websites with text and pictures were preferred over online-videos, and (b) the extent of intended usage for each modality did not differ between knowledge types with a low degree of spatiotemporal changes. This suggests that for knowledge types with a low degree of visuospatial changes, the modality preference during web-search is not affected by the knowledge dimension (procedural vs conceptual).

Online-videos were the preferred modality on a descriptive level for knowledge types with a high degree of spatiotemporal changes (SP and CC). However, this preference only reached significance for the procedural knowledge dimension with a high degree of spatiotemporal changes (SP tasks), but not for the conceptual knowledge dimension with a high degree of spatiotemporal changes (CC tasks). This suggests that the modality preference during web search could be affected by the knowledge dimension (procedural vs conceptual), specifically for knowledge types with a high degree of visuospatial changes.

4. Discussion

4.1. *The influence of knowledge types on modality preference in web search scenarios*

This research aimed to investigate how and to which degree the knowledge type of a learning task moderates a user's preference for a particular resource modality while searching for information on the web. For this purpose, like Urgo et al. [9,36] and Eickhoff et al. [35], we differentiated between conceptual and procedural knowledge dimensions (cf. [21]), which we, however, further subdivided into two underlying knowledge types per dimension. We observed an interaction between our knowledge types and modality. This observation can be interpreted as the first evidence that the characteristics of a knowledge type moderate the preference for potential resource modalities in hypothetical search scenarios. We found this moderating effect across two studies, and with two different operationalisations of modality preference. Moreover, in both studies, we did not observe a coherent pattern of modality selection within the two predefined knowledge dimensions of conceptual and procedural knowledge.

4.2. The degree of spatiotemporal changes in knowledge types

The absence of a coherent pattern of modality selection within the two predefined knowledge dimensions led us conclude that the differences in modality preferences between knowledge types might be moderated by an additional characteristic inherent in the learning tasks. As we have already proposed above, this might be the degree to which the display of spatiotemporal changes is relevant for the knowledge type.

The possibility that this factor plays a potential role in learning with different modalities is supported by the work of Ploetzner et al. [41]. They re-analysed the meta-analysis of Berney and Bétrancourt [43] that investigated the effectiveness of animations (i.e., a type of video) compared to static pictures for learning. The re-analysis showed that for certain tasks, such as learning about an optical phenomenon as a result of optical gravitational lensing [44] or learning about the Venus transit [45] for which the evident spatiotemporal changes (features of change, such as velocity, direction, or non-linear motion) were relevant to learning, animations were more beneficial for learning than pictures. Ploetzner et al. [41] concluded that this advantage might have resulted because animations can directly display such changes, whereas (a sequence of) static pictures "can at most indicate them" (p. 16). In contrast, for tasks where the display of spatiotemporal changes (e.g., learning about probability calculations [46]) was not identifiable as relevant features of change for learning, no differences were found between animations and pictures for learning. Following this thought, we categorised if spatiotemporal changes could be identified within our knowledge types which could be potentially beneficial for supporting learning. As outlined above, for sensorimotor procedural (SP) tasks, performing sensorimotor movements are necessary to complete the task. These movements are observable and result in changes of relations among entities (e.g., location, direction) that can be directly displayed in videos. In contrast, the processing steps necessary to solve cognitive procedural (CP) tasks are not directly observable. It is possible to externalise sub-steps visually, but this is just an abstract visualisation of results, for which visual changes across space and time don't need to be observed.

In causal conceptual (CC) tasks, causalities naturally lead to changes in properties or changes among entities, which can be displayed through spatiotemporal changes, as in animated videos. In contrast, in relational conceptual (RC) tasks, visual representations of concepts can be depicted mostly with static pictures due to the absence of spatiotemporal changes.

Based on this classification into high or low degrees of spatiotemporal changes observable in tasks, we further analysed differences within the knowledge types of the tasks. This exploratory approach provided additional insights: Namely, for tasks with a higher degree of spatiotemporal changes, a preference for dynamic representations, that is, videos, was observed. In contrast, a preference for static representations (texts with pictures) was observed for tasks with a low degree of spatiotemporal changes. Therefore, we argue that the degree to which the display of spatiotemporal changes is relevant for the knowledge type also impacts the modality preference of users.

In general, our findings indicate that the classification of knowledge according to the degree of visuospatial transformation can be helpful for the research of web-search behaviour. This is especially the case when multiple modalities are involved, and these findings should therefore be further examined in future research.

5. Practical and theoretical implications

As Vakkari [47] generally pointed out, more knowledge about the search process improves the systems supporting the search and their results. Therefore, as also Smith et al. [8] emphasised, considering the knowledge type of a task and the selection of a resource modality could generally inform complex models for understanding learners and helping systems support them. As an example, Eickhoff et al. [35] showed that search systems can use cue words (such as, “how to” or “what is”, to identify whether learners are looking for procedural or declarative knowledge dimensions in a search session.

Similarly, it might also be possible to classify the concrete knowledge type (or the relevance of visuospatial changes related to the search task) based on search query characteristics (e.g., a combination of query length and cue words) to inform the search system. Using these criteria, search engines could automatically identify the knowledge type of the task at hand. Our finding that modality preferences can differ across knowledge types suggests that the search engine could then use the identified knowledge type to offer corresponding modalities on the SERP.

A recommendation system implemented into a search engine, or a holistic model as described by Smith et al. [8], could use this information to support learners in search efficiency and maybe even in learning success. For example, learners searching for expository conceptual knowledge could receive more textual resources from the search engine in line with expected preferences. It is conceivable that this might also enhance their learning performance since prior research has indicated that for such kinds of tasks, textual resources are more advantageous for engaging in the cross-textual elaboration and information accumulation compared to videos [48]. In contrast, learners looking for sensorimotor procedural knowledge could receive more search results leading to video results in line with their preference. Again, this might enhance learning performance since dynamic visualisations (i.e., videos) compared to static visualisations have been shown to be particularly beneficial for learning sensorimotor procedures [49,50,51]. Yet, these assumptions of course still require empirical testing in future research.

Furthermore, information about learners' modality preferences or modality selection, respectively, during web search could also be used to investigate if clustering and categorisation of learner profiles [8] could be improved by considering the modality selection of learners. This would extend previous work, for example, by Binali et al. [52]. They differentiated between five clusters of online learners showing that the cluster of "moderately engaged, self-driven online viewers" (p. 8) differed from the other clusters by more frequently browsing web pages and especially viewing videos. In our view, future work could investigate whether, when considering different modalities and especially knowledge types, the found clusters can be replicated or whether users interact differently with the search system depending on our introduced factors of knowledge type and resource modality.

6. Limitations, future research and conclusion

The studies presented here were designed to use well-defined knowledge types and controlled tasks. However, participants were never confronted with actual search results or SERPs within the studies. Therefore, our results only reflect the selection intentions of users in a well-controlled scenario. It is known that when confronted with multiple search results on a SERP, users often apply simple heuristics, like the "top link" heuristic [53,12]. Concerning our selected topics, we used tasks from the fields of mathematics, physics, biology, and technology; further research could use topics related to other domains (e.g., arts or social science) to replicate our findings and show that not the domain of a task but rather the knowledge type behind a task is influencing the selection behaviour.

An additional point to consider regarding the samples of our studies is that the majority (77.8%) of participants were female. Thus, future studies should balance the sample. It could also be investigated whether gender-related differences in visuospatial working memory and spatial ability (cf. [54]) interact with the preference for particular resource modalities.

Further, since we only investigated users' initial and hypothetical selection preferences, it remains unclear whether the preference for a particular resource modality remains stable across the completion of a search task. Accordingly, future studies should investigate the influence of knowledge type, degree of spatiotemporal changes, and resource modality in a more realistic setup and observe the concrete selection behaviour and how this possibly changes during the search process. This would also allow the use of eye-tracking methodology to investigate the selection and evaluation behaviour of different modalities on SERPs for different knowledge types. Such procedures could deliver additional information helping to identify and categorise, for example, visual search patterns [55] that are unique to searching for specific knowledge types. The ability to automatically identify the knowledge type a searcher is looking for through eye-tracking or navigation logs could help design adaptive search systems (cf. [8]), which could support learners during search offers and provide, for example, task- and modality-related instructional scaffolding.

Nevertheless, we believe that a stepwise research approach to a realistic search scenario is beneficial for understanding how knowledge types and modalities interact on a fundamental level without additional influences (e.g., position within SERPs). Therefore, for future research on this topic, before examining more complex and authentic search scenarios, we recommend confronting participants in controlled settings where individual mocked-up search results differ in the resource modality they lead to (e.g., video search results vs. website search results).

The goal of the present work was to investigate the interaction between a task's knowledge type and the resource modality on users' preferences during web-based learning. Across two studies, we found that a task's knowledge type moderates the preference for different resource modalities. We found that the commonality of knowledge dimensions is not enough to predict the modality preference of users. This research also suggests that an additional task characteristic, the degree of spatiotemporal changes potentially influences modality preference during a web search.

Taken together, the present work provides interesting new insights into how the underlying knowledge type of search tasks influences the preference for video or website search results during a multimodal web search. As pointed out above, the influence of knowledge types on the preference for resource modalities adds promising new perspectives to future research and models addressing web search of learners, providing a more differentiated view on web search.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix C: Manuscript 3 (Experiment 4)

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RESEARCH ARTICLE

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The influence of knowledge type and source reputation on preferences for website or video search results

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Abstract

Searching for information on the web has become an essential task in our society. This article presents a preregistered experimental study that investigates how the knowledge dimension (conceptual, procedural) and relevance of displaying spatiotemporal changes (high, low) for a given search task affect searchers' preference for different resource modalities (websites, videos). Additionally, effects of source reputation (high, low) were examined. Participants were confronted with 16 learning tasks and respective mock-up video or website search results and had to indicate the likelihood of selecting the respective search results. The learning tasks varied regarding their knowledge dimension and their degree of spatiotemporal changes. Search results varied regarding source reputation and resource modality. Study results showed that search results with low source reputation were more likely to be selected when they were video results as compared to website results. Furthermore, for learning tasks with a high degree of spatiotemporal changes, a preference for videos over website results was found, while a low degree of spatiotemporal changes did not lead to modality preferences. To conclude, both knowledge dimension and degree of visuospatial changes of learning tasks seem to be promising classifications to consider for understanding users' source and modality selection during web-based learning.

1 | INTRODUCTION

Today, search engines are a major tool to assist learners in finding relevant information (Câmara et al., 2021), providing access to various information resources. While using search engines, different resource factors (e.g., the modality of the retrieved information or the reputation of the information source) and contextual factors (e.g., the knowledge type related to the task at hand) can influence users' search and selection behavior (Lazonder & Rouet, 2008; Lewandowski & Kammerer, 2021).

Since it has become easier to find not only text-focused websites (often combined with images) but also videos (e.g., from YouTube) for learning purposes during a web search (Feierabend et al., 2021; Smith et al., 2018), the factor of resource modality, that is, the type of modality (e.g., a website with text and images or a video) in which information is presented, has become more salient. The increased diversity of resource modalities available on the web is also reflected in recent design changes for search results on search engine result pages (SERPs). Often SERPs no longer include only the classic "10 blue links" in which search results are dominantly constructed through the modality of text (URL, title, abstract). Instead, search results differ in structure and design by integrating, for example, images or video thumbnails (Arguello, 2017;

Azzopardi et al., 2018; Kammerer et al., 2018; Wopereis & van Merriënboer, 2011).

Thus, the structure and integrated elements (e.g., images or video thumbnails) of search results can be used as cues to distinguish between search results leading to text-dominated websites and search results leading to videos, when deciding which search results to select from the SERP. This led us to our first research question: *To what extent and how does the resource modality indicated by a search result influence the likelihood of selecting the search result?* Specifically, we aimed to examine whether search results that indicate to link to a video as compared to a website differ in their likelihood of being selected for learning tasks. Building on this question, we also sought to investigate whether other resource and contextual factors would moderate this likelihood of selecting different resource modalities indicated in search results.

In addition to resource modality, another resource factor that we sought to investigate is *source reputation* (cf. Choi & Stvilia, 2015; Unkel & Haas, 2017). With the term "source" we refer to the origin (e.g., a person or institution) of a resource (e.g., a website or video). Thus, while the resource is the complete artifact that users can access, the source refers to the entity that has provided the resource. On the web, anybody can publish information. Thus, identifying search results that lead to information provided by sources of high reputation (i.e., of high credibility) is essential (Haas & Unkel, 2017). One way to identify sources of high reputation is to consider cues within search results, such as information about the author or the URL (Choi & Stvilia, 2015). This is also how we manipulated source reputation in the present study. We compared sources of high and low reputation, as indicated by cues within search results. This allowed us to investigate whether the degree of source reputation affects the selection of website search results as compared to video search results. Recent research showed that when confronted with different kinds of learning resources, participants rated information presented through video as more credible (Liu et al., 2010; Wittenberg et al., 2021) and showed higher engagement (Yadav et al., 2011) than when being confronted with text. These effects might also increase the likelihood of selecting videos even when provided by sources of low reputation.

In addition, the likelihood of selecting a video or website result might also be moderated by the contextual factor of knowledge type underlying a learning task (cf. Pardi et al., 2023). On the web, learners search for all kinds of information from various domains related to different knowledge types, such as relational conceptual knowledge (e.g., how concept X and concept Y relate) or sensorimotor procedural knowledge (e.g., how to tie a knot). Thus, with the term "knowledge types" we refer to sub-categories of knowledge dimensions (specifically conceptual and procedural knowledge). Furthermore, knowledge types can also differ in the degree to which the display of spatiotemporal changes, that is, dynamic processes, is relevant for learning (Ploetzner et al., 2020). Building on previous research by Pardi et al. (2023), in the present work, we investigated how the *knowledge type of a task* and, more specifically, the *degree of spatiotemporal changes* relevant to the task moderate the likelihood of selecting video or website search results.

To investigate our research questions, participants were confronted with a set of hypothetical search tasks of different knowledge types. Furthermore, for each task, they were shown single search results (not on a SERP), which differed in modality (website or video) and source reputation (high or low, see Table A1 of the appendix). For each search result, they had to indicate the likelihood of selecting it to complete the respective search task.

In the following, we will review previous work on the two resource factors of resource modality and source reputation, the contextual factor of knowledge type, and how they can affect search result selection. Yet, to our knowledge, no previous work has examined the interactive effects of knowledge type, resource modality, and source reputation in search result selection.

2 | BACKGROUND AND RELATED WORK

2.1 | Resource factors

Previous studies investigated how the search result rank (Kammerer & Gerjets, 2014; Pan et al., 2007) or the additional presentation of answer modules displayed as featured snippets on the SERP (Wu et al., 2020) or of additional information presented in the right rail of the SERP (Shao et al., 2022) affected users' evaluation and selection behavior. In contrast, the focus within this work lies on two factors that are presented as part of the search results: (a) the modality of the resource (e.g., text or video) to which a search result links to, and (b) the reputation cues presented in a search result that indicate whether a credible or less credible source provides the information.

2.1.1 | Resource modality

The factor of resource modality can be investigated in two ways: either with regard to the representations that are presented as part of the search result (cf. Capra et al., 2013; Hughes et al., 2003) or with regard to the expected modality of the resource behind the search result (cf. Pardi et al., 2023).

Following the first approach, Hughes et al. (2003) investigated the effect of including three images next to the textual description of each search result in a video-only SERP. They found that participants fixated longer on textual elements (title and description) than on the displayed images. Derived from visual scan paths, they concluded that participants used textual elements as an anchor to judge the search results but that searchers also fixated on integrated images. Like Hughes et al. (2003), Capra et al. (2013, Study 1) investigated the effect of images within search results on users' relevance judgments. In the first study, single search results were presented, and participants judged whether the search result would lead to a *useful* or *not useful* website. Specifically, the authors investigated whether search results without (text-only) and with images (bad, mixed, and good images) led to differences in the accuracy of judgments regarding the relevance of search results. They found a small but significant effect of images increasing the accuracy of relevance judgments by 2.3% when the included images were strongly related to the websites' main content (good images). In a second study, in which they investigated the effect of images on the SERP level, including images in search results had no effect. Also, good images in search results did not lead to significant differences compared to the text-only results.

Following the second approach, Pardi et al. (2023) investigated which role the modality of the resource to which the search result links to plays for learners. Specifically, they investigated what resource modalities, for examples, websites with text and images or online videos, learners would hypothetically prefer when searching for information about different learning tasks. The results showed that the preference for a resource modality was moderated by the knowledge type underlying the learning task (see Section 2.2.3). Furthermore, Pardi et al. (2022) investigated how learners used different resource modalities during a free web search-based learning setting. With the help of eye-tracking, they investigated to which degree the different resource modalities were used while learning about the formation of thunderstorms and lightning. They found that most learners concentrated significantly longer during learning on text (54.39% of fixation time) than on videos, but that videos also played an essential role (38.99% of fixation time) in contrast to images (6.66% of fixation time).

In the present research, we consider both approaches by investigating the effect of modality in two ways: first, by examining the effects of images that are presented as part of the search result design (cf. Capra et al., 2013); and second, by examining the effects of the resource modality by comparing the likelihood of selecting website search results as compared to video search results (cf. Pardi et al., 2023). This allows us to investigate whether the design of search results and/or the expected resource modality behind the result affect the likelihood of selection.

2.1.2 | Source reputation

Haas and Unkel (2017) investigated the effect of source reputation within search results on users' credibility ratings and selection behavior. The source was displayed within the URL of search results and informed the user about the origin of the information. Source reputation was varied by using well-known reputable newspapers and research institutes as sources with high reputation, while companies and blogs functioned as sources of low reputation. The study revealed that search results leading to newspaper or research institute websites were perceived as more credible than those leading to company sites or blogs. Furthermore, search results leading to newspaper sites were more likely selected than search results leading to company websites. Yet, this difference was relatively small compared to the strong effect that the rank of the search result on the SERP had on users' selection decisions. Another study by Unkel and Haas (2017) investigated the influence of source reputation, message neutrality, and social recommendation as reputation cues on users' selection of search results on SERPs. Again, they found a strong effect of search result rank. Only the variation of a source's reputation (well-known institutional sites vs. little known personal sites), as reputation cue variation, showed an additional effect on the search result selection.

In the abovementioned studies, however, the judgment of source reputation was not investigated for different resource modalities. Generally, investigating whether the modality influences the perceived credibility of a source so far seems to be a relatively neglected field, especially in the context of web searches. An exception is the work by Wittenberg et al. (2021), who found, across two studies, that the presented information was perceived as more believable for learners confronted with a video than for learners confronted with a text in the context of political and health-related topics. One other study by Marttunen et al. (2021) showed that secondary school students performed poorly in justifying their evaluation of credibility and argumentative content of both video and text-based online sources. However, participants showed even poorer performance in justifying why a source was less credible for a video resource than for a text resource.

2.2 | Contextual factors

The definition of contextual factors comprises "[...] all relevant characteristics of the situation (place, time, equipment, people and messages) that pre-exist to the search activity" (Lazonder & Rouet, 2008, p. 756), which also includes the consideration of task types or task instructions (cf. Lewandowski & Kammerer, 2021). Studies considering the task type as a contextual factor found that differences in task complexity or task topic (e.g., Hienert et al., 2018; Liu et al., 2010) influence learners' web search behavior (e.g., total completion time, number of visited resources).

In the present article, we want to emphasize that beyond a specific task type and topic, the underpinning knowledge dimension or the knowledge type can influence learners' preferences for different resource modalities.

2.2.1 | Knowledge dimensions

Previous classifications of knowledge into the overarching constructs of knowledge dimensions often differentiate between factual, conceptual, and procedural knowledge (cf. Anderson et al., 2014). While factual knowledge deals with single bits of information (e.g., terminology, specific details), tasks related to the conceptual knowledge dimension comprise complex knowledge about "[…] categories and classifications and relationships between and among them […]" and also "[…] includes schemas, mental models, or implicit or explicit theories […]" (Anderson et al., 2014, p. 48). In contrast, tasks belonging to the procedural knowledge dimension comprise "know how to do it"-knowledge that encompasses knowledge about independent production rules related to different problem states and how to solve them (Corbett & Anderson, 1995).

Few studies have considered the role of knowledge dimensions as a contextual factor while seeking information on the web. Eickhoff et al. (2014) showed that the underlying knowledge dimension of a search task influences the search and interaction behavior during web searches. Within search sessions with a procedural intent, searchers increased the average time spent reading toward the end of the session compared to search sessions with other intents. Also, search queries contained different cue words depending on the search intent. Example cue words for procedural tasks were "how to" or "how do I," while for declarative searches, terms like "what is" or "who" were favored.

Urgo et al. (2020) investigated how a learning task's underlying knowledge dimension influenced learners' search behavior. Adapted from Anderson et al. (2014), they used the factual, conceptual, and procedural knowledge dimensions. They found that learners perceived a greater need for facts during factual, a greater need for concepts during conceptual, and a greater need for procedures during procedural knowledge tasks. The levels of cognitive activity were perceived as different between task types. While procedural knowledge tasks involved more "applying," "evaluating," and "creating," conceptual knowledge tasks were perceived to involve more "understanding" and "analyzing" activities. Furthermore, procedural knowledge tasks were perceived as less complex than conceptual knowledge tasks. Likewise, when looking at the specific search behavior, more queries were entered for conceptual tasks than for procedural tasks, and it took longer to complete the former tasks.

2.2.2 | Subtypes of knowledge dimensions

Pardi et al. (2023) investigated how learning tasks belonging to the conceptual and procedural knowledge dimensions influenced the preference to select different resource modalities (text with images, text only, image only, or video) in hypothetical search scenarios. For both knowledge dimensions, they introduced two subtypes.

For the conceptual knowledge dimension, they examined *causal conceptual (CC) knowledge* and *relational conceptual (RC) knowledge*. Both have in common that they encompass complex information regarding the categorization and classification of concepts and how these concepts relate to each other (cf. Anderson et al., 2014). Causal conceptual knowledge refers to knowledge about cause-and-effect chains between and within different concepts (van Genuchten et al., 2012). Relational conceptual knowledge refers to how at least two different concepts (e.g., rabbits and hares) relate to each other (Gentner, 2005; van Genuchten et al., 2012) without directly interacting through causality.

Within the procedural knowledge dimension, Pardi et al. (2023) differentiated between *sensorimotor procedural (SP) knowledge* and *cognitive procedural (CP) knowledge*. Both encompass knowledge of "how to do it" (cf. Mc Cormick, 1997). Sensorimotor procedural knowledge refers to knowledge about how to solve a task involving motoric movements. Cognitive procedural knowledge refers to knowledge about cognitive operations required to solve a procedural task for which no direct physical or motoric action is needed. Carlson and Lundy (1992) defined the process of solving mathematical problems as an example of cognitive processes.

Pardi et al. (2023) found that for relational conceptual (RC) tasks, participants preferred the modality of text with images. In contrast, no clear preference for text with images or videos was found for causal conceptual (CC) tasks. Furthermore, sensorimotor procedural (SP) tasks led to a preference for videos. In contrast, cognitive procedural (CC) tasks did not lead to a preference for one of the two modalities. Based on these results, Pardi et al. (2023) concluded that another characteristic of the learning task influences the modality preference in addition to the knowledge dimension, namely, the degree to which the display of spatiotemporal changes is relevant for a knowledge type. Previous work by Ploetzner et al. (2020) indicated that this factor moderates the effectiveness of different resource modalities for learning, such that for tasks for which the display of spatiotemporal changes is relevant to learning, animations (i.e., videos) were more beneficial than static pictures. In contrast, for tasks for which the display of spatiotemporal changes was not relevant, no differences were found between animations and pictures for learning.

2.2.3 | Knowledge types and degree of spatiotemporal changes

Spatiotemporal changes generally comprise visual or depictable changes in shape, size, location, direction, or speed (Tversky, 2005). Following this definition, Pardi et al. (2023) suggested that displaying spatiotemporal changes is relevant for both causal conceptual and sensorimotor procedural knowledge. For causal conceptual knowledge (e.g., the formation of thunderstorms), causalities naturally lead to changes of properties (e.g., size or color) or changes between entities (e.g., distance, speed) which can be displayed through spatiotemporal changes. Sensorimotor procedural knowledge (e.g., how to apply a pressure bandage to the hand) is knowledge about performing sensorimotor movements. These movements are observable and result in changes in relations between entities, that is, spatiotemporal changes.

In contrast, displaying spatiotemporal changes for relational conceptual and cognitive procedural knowledge can be considered to be of low relevance (Pardi et al., 2023). For relational conceptual knowledge, no changes of properties or entities are perceivable over time. Cognitive procedural knowledge (e.g., calculating a prism's volume) is knowledge about performing cognitive operations that are not directly observable. Although it is possible to visualize, for example, mathematical equations and their evolvement, it remains just an abstract visualization of results, for which visual changes across space and time do not necessarily need to be represented for understanding.

Pardi et al. (2023) conducted exploratory analyses based on these assumptions. Results indicated that websites with text and images were preferred over online-videos for knowledge types identified as having a low degree of spatiotemporal changes (RC and CP). In contrast, on a descriptive level, online-videos were the preferred modality for knowledge types with a high degree of spatiotemporal changes (CC and SP). However, this preference only reached significance for sensorimotor knowledge tasks but not for causal conceptual tasks.

3 | PRESENT STUDY

Based on Pardi et al. (2023), the present study aimed to investigate how the initial likelihood of selecting a search result is influenced by aspects of the contextual factor knowledge type and the resource factor resource modality. Additionally, source reputation was manipulated within this study as another resource factor. Methodologically, in contrast to Pardi et al. (2023), who only provided verbal descriptions of resources (e.g., "an online video" or "a website with text and pictures"), in the present study, actual search results of different resource modalities with varying source reputation were presented to participants. However, as in Pardi et al. (2023), no actual web searches had to be conducted. Instead, hypothetical search tasks were formulated for the four knowledge types of sensorimotor procedural, cognitive procedural, causal conceptual, and relational conceptual knowledge. Participants had to rate how likely they would select the presented search results when using the web to learn about these tasks. Thus, by applying this experimental scenario, other contextual factors, like the ranking of a search result on a SERP, could not influence the likelihood of selection (cf. Capra et al., 2013, Study 1).

We derived the following hypotheses based on the theoretical considerations and prior empirical findings outlined above.

Our first hypothesis (*H1*) was that differences in the reported likelihood of selecting a video compared to a website search result, depend on the underlying knowledge type of the learning task or, more specifically, on the relevance of displaying spatiotemporal changes for the knowledge type. Our specific hypothesis was as follows: For tasks with a high degree of spatiotemporal changes, there should be a higher likelihood of selecting a video search result over a website search result than for tasks with a low degree of spatiotemporal changes. On the level of individual knowledge types, based on the findings of Pardi et al. (2023), we expected a preference for video over website search results within SP and CC tasks, while no difference should be present within CP and RC tasks.

Our second hypothesis (*H2*) was that differences in the reported likelihood of selecting a video compared to a website search result depend on the source reputation of the search result. Specifically, we expected no difference between the likelihood of selecting a video or website search result of high source reputation. This was based on the assumption that, generally, participants can correctly assess the source reputation of a search result when cues indicating high credibility are included (Haas & Unkel, 2017), regardless of the modality. In contrast, the modality effects (described in H1) should be observed in favor of videos for search results with low source reputations, in line with previous research that showed higher trust in videos (Wittenberg et al., 2021) and a decreased ability of learners to identify non-credible video results compared to website results (Marttunen et al., 2021).

As a control hypothesis (*H3*),[1] we included the assumption that differences in the reported likelihood of selecting a video compared to a website search result depend on the presentation of images as a part of the search result. This control hypothesis was included to rule out that not the perceived resource modality as such, but the presence or absence of an image as part of the search result influences the decision to select a video or a website. However, it should be noted that Capra et al. (2013), who investigated the effect of incorporating images in text-based surrogates, did not find a general effect of images improving the accuracy of relevance judgments of search results. Also, Hughes et al. (2003) argued that participants used text-based information rather than the included images to judge search results.

4 | METHODS

4.1 | Participants

The study was conducted with 230 German participants recruited through Prolific (Prolific, London, UK) who were between 18 and 35 years old with at least a high school diploma. Participants were reimbursed with £2.20 (*Md* of participation time = 12:09 min). One participant was excluded due to failing to indicate the correct resource modality in 15 out of 32 times, resulting in a final sample of 229 participants (143 male, 85 female, 1 diverse, M_{age} = 26.31 years, SD_{age} = 4.47 years). An a priori power analysis indicated that with 220 participants, a power (1-β err prob) of 0.80 would be exceeded for our weakest expected effect.

4.2 | Study design

The study used a 4 × 2 × 2 × 2 mixed design with three within-subject factors and one between-subjects factor. The within-subject factors were knowledge types (sensorimotor procedural, cognitive procedural, causal conceptual, and relational conceptual), source reputation (high, low), and resource modality (website, video). The presence or absence of images within search results was manipulated as a between-subject factor (with-image, without-image).

4.3 | Tasks

Participants were confronted with 16 hypothetical learning tasks (four tasks per knowledge type, see Tables A2 and A3 of the appendix). Each of the 16 tasks was related to one of four domains: mathematics, physics, biology, or technology. Participants were shown two search results for each learning task, one video search result and one website search result. Each search result was presented separately on a page. All used resources had high task relevance and were suitable for solving the respective tasks.

Since participants were presented with two search results for each task, each task was presented twice in two separate blocks (in one block with a video search result and in the other block with a website search result). Within each block, the 16 tasks were presented in randomized order. Source reputation (high, low) was also counterbalanced for each participant for each task across the two blocks. For example, if a participant was shown a website result with low source reputation for the sensorimotor procedural task "how to tie a double figure eight knot" in the first block, they received a video result with high source reputation for this task in the second block.

4.4 | Search result material

Search results were manipulated regarding the indicated resource modality (video, website) and source reputation (high, low). Beyond that, participants were randomly assigned to the with- or without-images group for the between-subjects factor of images.

4.4.1 | Structure of video and website search results

We used the original HTML structure of video and website search results presented on Google SERPs to create realistic but mocked-up search results (see Figure 1). The title and abstract information were identical in the two modalities. A static image with a play button and a timeline (without presenting any time information about duration) was included in video search results. This decision was made to avoid participants using cues regarding time investment in their selection decision.

The website results presented the URL above the title, indicating the source that provided the information. In the video search results, above the title the platform where the video is hosted, in our case YouTube, was presented. The specific information about the video source was indicated by an "Uploaded by …" statement below the abstract.

4.4.2 | Source reputation

Source reputation was manipulated as follows: For sources of high reputation, commonly known sources (e.g., German Red Cross) with high standing or sources with institutional qualification (e.g., institute, university) were used. In contrast, unknown or personal sources (e.g., blogs) were used for sources of low reputation. The sources of high and low reputation were selected based on a pre-test with 25 university students ($M = 25.20$, $SD = 3.06$, 19 females, 6 males), who were asked to rate the reputation of at least four different sources for each search result on a scale ranging from 1 = "not at all [reputable]" to 7 = "very [reputable]" for the respective learning tasks. For each search result, pairs of sources that differed significantly in their indicated reputation were selected.

4.4.3 | Presentation of images

In the without-image condition, we used standard website search results (see Figure 1, top left). For video search results, in the without-image condition, we presented a thumbnail showing a play button and a video timeline on a gray surface (Figure 1, top right). In contrast, for video search results in the with-image condition, as typical for video previews, we presented a thematically relevant image with a play button and a timeline overlayed (Figure 1, bottom right). For website search results in the with-image condition, we presented the same image (but without the play button and timeline) left to the abstract (Figure 1, bottom left).

4.5 | Procedure

The study was conducted online using the survey platform Qualtrics (Qualtrics, Provo, UT). The study could only be accessed via a desktop web browser. After giving informed consent, participants provided their demographics and self-assessed their prior knowledge regarding the 16 learning tasks on a 7-point scale from "1 = no knowledge at all" to "7 = very good knowledge." To this end, all 16 learning tasks were presented in a list (in randomized order) to the participants. Self-reported prior knowledge was averaged across the four tasks for each knowledge type. Participants were then informed that they would be confronted with 32 tasks for different learning topics. They were encouraged to imagine that they would have to learn enough to solve the task by using a search engine (e.g., Google) to find pertinent information. Each learning task was introduced with the sentence: "Imagine that you should learn with the help of the Internet …" followed by the learning task and ending with the sentence "Imagine further that you come across the following search result during your search." Below, the corresponding search result was presented. For each combination of learning task and search result, participants were asked to indicate (a) how likely they would select the displayed search result on a 7-point scale from 1 = "not at all" to 7 = "very" and (b) whether the search result leads to a website or a YouTube video (as a manipulation check).

4.6 | Dependent measure

As the dependent variable, for each of the four knowledge types, we calculated the average likelihood of selection for the presented video and website search results by averaging the indicated likelihood across the four tasks. Higher scores indicate a greater likelihood of selecting the search result.

4.7 | Analytic approach

A mixed-model regression analysis conducted in R (RStudio, 2020) using the lme4-package (Bates et al., 2015) was calculated. The main and interaction effects of the within-subject factors (knowledge type, resource modality, source reputation) and between-subject factor (presence of images) were included in the model. To investigate H1, we used preregistered planned contrasts, comparing the knowledge types as to whether they do (SP, CC) or do not (CP, RC) address spatiotemporal changes (Contrast 1 coded: SP: 1, CC: 1, CP: −1, RC: −1). As subsequent contrasts, we compared procedural and conceptual knowledge within knowledge types addressing a high degree of spatiotemporal changes (Contrast 2 coded: SP: −1, CC: 1, CP: 0, RC: 0) and a low degree of spatiotemporal changes (Contrast 3 coded: SP: 0, CC: 0, CP: 1, RC: −1).

5 | RESULTS

First, we analyzed whether the with-image and the without-image conditions were comparable regarding age, gender, and prior knowledge. The two groups did not differ in their age (with-image condition: $M = 26.27$, $SD = 4.44$; without-image condition: $M = 26.35$,

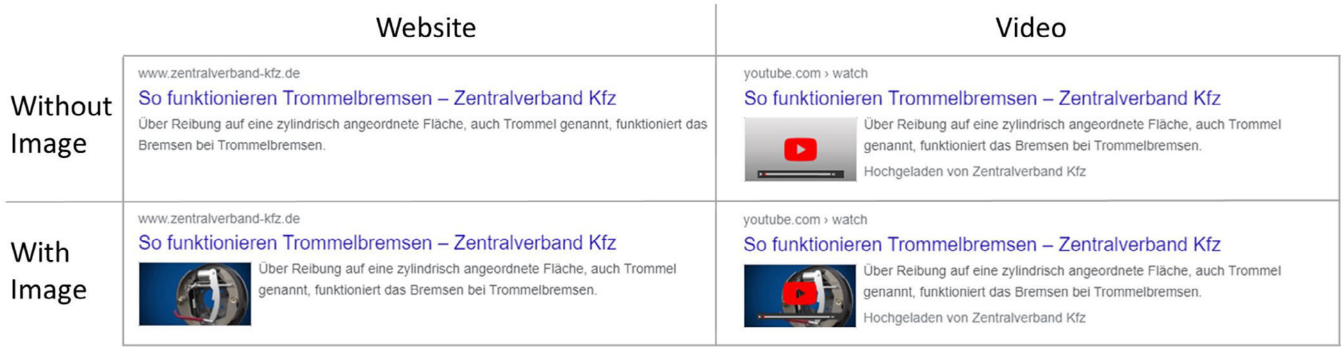

FIGURE 1 Website and video search results with and without images.

SD = 4.52; $t[227] = -0.13$, $p = 0.898$) or in their gender distribution (with-image condition: 71 male; without-image condition: 69 male, $X^2[2, 299] = 1.46$, $p = 0.481$). For self-assessed prior knowledge, for the cognitive procedural (CP) knowledge tasks, an analysis of variance (ANOVA) revealed a significant difference between the with-image ($M = 2.91$, SD = 1.55) and no-image ($M = 2.56$, SD = 1.44) conditions, $F(1,3) = 4.79$, $p = 0.002$.[2] No differences between the with-image and the without-image conditions were found for self-reported prior knowledge for the tasks of the three other knowledge types (all $p > 0.999$). Overall, participants indicated low to medium prior knowledge of the topics of the different task types ($M = 3.16$, SD = 0.93).

Furthermore, before testing our hypotheses, we calculated model comparisons to ensure that no additional variance was explained by including three-way interactions. Neither including all possible three-way interactions between the within-subject factors into the model, $\chi^2(3) = 0.20$, $p = 0.978$, nor including all possible four-way interactions, considering the between-subject factor image, $\chi^2(13) = 8.61$, $p = 0.569$, added significant explanation of variance to the model. Our mixed-model regression analysis indicated that our predictors explained 58.8% of the variance ($R^2 = 0.59$) within the data.

For the main effects underlying our assumed interactions, we found a main effect of resource modality favoring video ($M = 5.54$, SD = 1.30) compared to website search results ($M = 5.10$, SD = 1.34), $b = 0.22$, $t(221) = 6.15$, $p < 0.001$, $r = 0.38$. Also, a main effect of source reputation was found, favoring search results with high reputation ($M = 5.41$, SD = 1.34) over results with low reputation ($M = 5.23$, SD = 1.32), $b = 0.25$, $t(176) = 8.52$, $p < 0.001$, $r = 0.54$.

Regarding our control hypothesis (H3), neither the main effect of image ($p = 0.928$) nor the interaction with resource modality ($p = 0.061$) was significant. This indicated that neither integrating an image into a video nor into a website search result influenced the likelihood of selecting a search result. The likelihood of selection, calculated as a function of knowledge type, image, and source reputation is shown in Table A4.

5.1 | Interaction between spatiotemporal changes and resource modality on the likelihood of search result selection (H1)

A model comparison of the mixed-model regressions revealed an increase in explained variance when the interaction between resource modality and knowledge type was included in the model, $\chi^2(3) = 269.78$, $p < 0.001$.

We further investigated this interaction with our first planned contrast (C1), summarizing knowledge types with a high (SP, CC) and a low (CP, RC) degree of spatiotemporal changes and the difference in modality preference. The analysis showed, as expected, a significant interaction between this contrast and resource modality regarding search result selection, $b = 0.21$, $t(2325) = 14.89$, $p < 0.001$, $r = 0.30$. Beyond the interaction, also the main effect for the first contrast (spatiotemporal changes) reached significance, $b = 0.09$, $t(617) = 5.89$, $p < 0.001$.

Investigating the interaction in more detail, pairwise comparisons (Figure 2) showed a higher likelihood of selecting videos ($M = 5.83$, SD = 1.13) compared to websites ($M = 4.98$, SD = 1.39) for knowledge types with a high degree of spatiotemporal changes, $b = 0.85$, $t(397) = 11.32$, $p < 0.001$, $r = 0.49$. In contrast, no difference ($p > 0.999$) between the likelihood of selecting videos ($M = 5.25$, SD = 1.37) and the likelihood of selecting websites ($M = 5.22$, SD = 1.29) was found for knowledge types with a low degree of spatiotemporal changes.

We further investigated the interaction of our second planned contrast (C2), knowledge types (CC, SP) with a

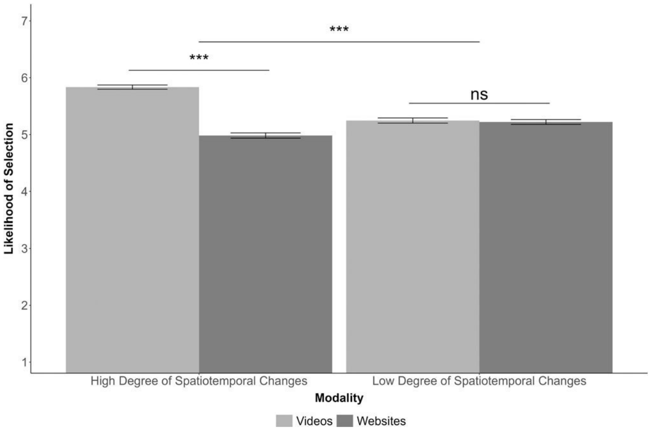

FIGURE 2 Likelihood of search result selection depending on resource modality and the degree of spatiotemporal changes. ***$p < 0.001$. Error bars represent standard errors.

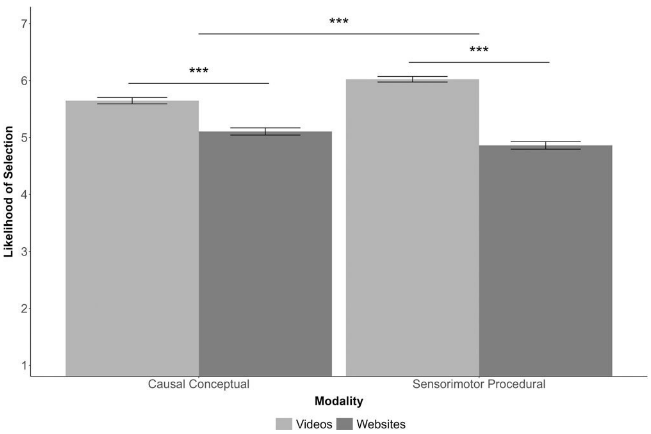

FIGURE 3 Likelihood of search result selection depending on the resource modality and knowledge dimensions with spatiotemporal changes. ***$p < 0.001$. Error bars represent standard errors.

high degree of spatiotemporal changes, and the difference in modality preference (Figure 3). Against our expectation, the interaction between resource modality and the knowledge types of the second contrasts reached a significant level, indicating that beyond the degree of spatiotemporal changes also the knowledge dimension (conceptual, procedural) influenced the likelihood of selection, $b = 0.16$, $t(2325) = 7.91$, $p < 0.001$, $r = 0.16$. The main effect of the second contrast (CC vs. SP) did not reach significance ($p = 0.112$).

However, as expected, for the CC tasks, the post hoc tests revealed a significantly higher likelihood of selection for videos ($M = 5.65$, $SD = 1.18$) than for websites ($M = 5.10$, $SD = 1.35$), $b = 0.54$ (95% CI, 0.27, 0.81), $t(629) = 6.30$, $p < 0.001$, $r = 0.24$. The same pattern was found for SP tasks, where also a significantly higher

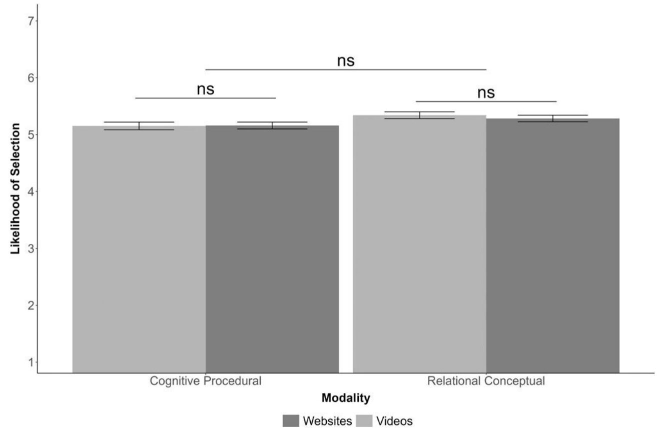

FIGURE 4 Likelihood of search result selection depending on the resource modality and knowledge dimensions with a low degree of spatiotemporal changes. Error bars represent standard errors.

likelihood of selection was indicated for videos ($M = 6.02$, $SD = 1.04$) than for websites ($M = 4.86$, $SD = 1.43$), $b = 1.16$ (95% CI, 0.89, 1.43), $t(629) = 13.51$, $p < 0.001$, $r = 0.47$.

In our third planned contrast (C3), we compared knowledge types with a low degree of spatiotemporal changes (CP, RC) regarding the difference in modality preference (Figure 4). In line with our expectation, the interaction between resource modality and the knowledge types of the third contrast failed to reach a significant level ($p = 0.404$). The main effect of the contrast (CP vs. RC) reached a significant level, $b = 0.07$, $t(617) = 3.71$, $p < 0.001$, $r = 0.15$. For both CP and RC tasks, no significant differences (both $p > 0.999$) were found between the indicated likelihood of selecting website search results or video search results.

5.2 | Influence of source reputation and modality on the likelihood of search result selection (H2)

In line with our hypothesis, the interaction between source reputation and resource modality (Figure 5) was significant, $b = 0.04$, $t(2325) = 2.62$, $p = 0.009$, $r = 0.05$. Against our expectation, Bonferroni corrected post hoc tests showed a significantly higher likelihood for selecting video results ($M = 5.75$, $SD = 1.19$) than website results ($M = 5.38$, $SD = 1.31$) when source reputation of the presented results was high, $b = 0.37$ (95% CI, 0.57, 0.16), $t(407) = 4.78$, $p < 0.001$, $r = 0.23$. At the same time, the expected significant advantage for video results ($M = 5.33$, $SD = 1.35$) over website results ($M = 4.82$, $SD = 1.31$) was found when source reputation of the

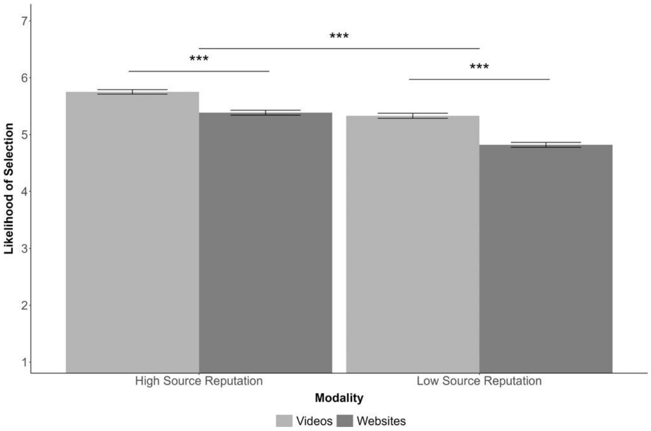

FIGURE 5 Likelihood of search result selection depending on the resource modality and source reputation. ***$p < 0.001$. Error bars represent standard errors.

presented search results was low, $b = 0.51$ (95% CI, 0.71, 0.31), $t(407) = -6.68$, $p < 0.001$, $r = 0.32$.

6 | DISCUSSION

We investigated how the initial likelihood of selecting a website or a video search result is influenced by the two resource factors of resource modality and source reputation and the contextual aspect of knowledge dimension (procedural vs. conceptual). More precisely, we further distinguished knowledge types based on their degree of spatiotemporal changes.

6.1 | The interplay between resource modality and knowledge type

In line with our first hypothesis (H1), we replicated the results of Pardi et al. (2023), showing that the contextual factor of knowledge type of a learning task influences the likelihood of selecting a search result of a particular resource modality. We found that the differences between knowledge types with a high (CC, SP) and low degree of spatiotemporal changes (RC, CP) interacted with the resource factor of modality. In particular, for knowledge types with a high degree of spatiotemporal changes, we observed a higher likelihood of selection for video search results than for website search results. In contrast, no differences were found for knowledge types with a low degree of spatiotemporal changes for the likelihood of selecting a video or website search result.

To conclude, our results indicate that the contextual factor "knowledge type" or "degree of spatiotemporal changes relevant to a knowledge type", respectively, can influence learners' selection behavior during online searches. Transferring these findings into theoretical models that further break down the process of searching for, finding, and learning information on the internet (e.g., Walraven et al., 2008) could be a promising next step in better understanding the online search processes.

One practical implication of our findings could be the automated detection of the knowledge type of search tasks. To achieve this, the system could analyze the information about the modality selection pattern of searchers and their used search queries. Since Eickhoff et al. (2014) showed that queries for procedural and conceptual knowledge differ, the search query could be used to determine the knowledge dimension underlying a search task. Further, whether a video or website has been selected as a modality could inform the system on whether the knowledge type underlying a search task is one for which the display of spatiotemporal changes is of high or low relevance. Systems could personalize search results and offer systematic scaffolding based on such information.

Based on our findings, it seems reasonable to assume that the knowledge type underlying a learning task influences learners' modality preferences during the evaluation and selection phase of the search results. Our results indicate that learners' preference for a particular resource modality depends on the degree to which the display of spatiotemporal changes is relevant to the learning task. Therefore, no general modality preference was found.

Essential to mention is that the results of our control hypothesis (H3) ruled out that an effect of images presented as part of the search results is responsible for the observed effects on resource modality selection. No significant main effect or interaction effects of the presentation of images as part of the search result were observed. Therefore, the effects on selection likelihood seem to be based on the expected modality of the resource to which the search result links to and not on the integration of different modalities within the representation of the search result in the SERP. This aligns with previous research (Arguello & Capra, 2012; Capra et al., 2013; Hughes et al., 2003).

6.2 | The interplay between resource modality and source reputation

Generally, a higher source reputation was associated with a higher likelihood of selection. This result is in line with Haas and Unkel's (2017) findings that searchers can correctly assess source reputation based on cues within search results and also fits in with previous research showing that reputation indicators can be used in selecting and evaluating information in online contexts (Gottschling et al., 2020). In line with our second hypothesis (H2), we found an interaction between source reputation and resource modality. While there was a preference for videos over websites (based on the advantage in the CC and SP knowledge types), this difference was more pronounced within search results of low source reputation than results of high source reputation. This could be interpreted, in line with the results of Marttunen et al. (2021) and Wittenberg et al. (2021), that learners' correct assessment of source reputation potentially differs between modalities, especially when the source reputation is low. However, the observed interaction could also be due to a ceiling effect. Search results with high source reputation generally received very high ratings for the likelihood of selection, potentially leaving less room for modality preference effects compared to results of low source reputation. Nonetheless, based on our observations, we argue that future research should further investigate the effect of resource modality in combination with perceived source reputation.

6.3 | Limitations and future work

While the well-controlled material and study environment allowed an unconfounded investigation of the effects of resource modality, source reputation, and knowledge types, they also brought limitations regarding generalizability. First and foremost, the search results were not presented on a SERP. Therefore, participants could not use the well-known "top rank" heuristic, which assumes that searchers predominantly consider and select the top-ranked search results on a SERP (Haas & Unkel, 2017; Pan et al., 2007; Salmerón et al., 2013). Further, since we only investigated users' initial and hypothetical selection preferences, it remains unclear whether the preference for a particular resource modality remains stable across the completion of a search task. Hence, more research is needed to examine to which degree the results of the present research can be generalized to more realistic settings with search results being presented on SERPs (e.g., Haas & Unkel, 2017) or even when examining an open web search (e.g., Pardi et al., 2022). Within such a naturalistic setting, it would be possible to investigate which resource modality users prefer during multiple-search sessions of different knowledge types. It could also be analyzed whether the initial selection decision for a modality and the following resource selection show a pattern of consistency across and within knowledge types.

Another limitation of this study is that it concentrated only on resource and contextual factors potentially influencing the selection behavior of learners. Following the classification by Lewandowski and Kammerer (2021), individual factors such as prior knowledge (e.g., Liu & Zhang, 2019; Sanchiz et al., 2017), age (e.g., Bilal & Gwizdka, 2016; Singer et al., 2012), or gender (e.g., Singer et al., 2012) may also play a role in search result selection and should be considered. For example, Liu and Zhang (2019) found that participants selected different sets of documents depending on their prior knowledge. Lower prior knowledge increased the likelihood of simply selecting top-ranked search results. Therefore, we argue that future studies should investigate how differences in prior knowledge interact with the modality selection preferences and knowledge types. Also, the role of age and gender should be further investigated in controlled settings since our study sample was relatively young and the majority (62.45%) was male. For instance, future work could investigate whether gender-related differences in visuospatial working memory and spatial ability (cf. Wang & Carr, 2014) or age differences interact with the preference for particular resource modalities.

Despite these limitations, we believe that the presented research offers exciting and relevant new findings for understanding the selection behavior of learners regarding different modalities in interaction with different task types.

7 | SUMMARY AND CONCLUSION

We investigated how and to which degree contextual factors (knowledge type and the degree of spatiotemporal changes underlying a knowledge type) and resource factors (resource modality and source reputation) and their interplay affect the likelihood of selecting a search result when being confronted with hypothetical learning tasks. In line with Pardi et al. (2023), the knowledge type underlying a learning task moderated the likelihood of selecting a video or website search result.

This has important implications for research on online search behavior and the interpretation of findings in this context. For example, in our study, without considering the interaction of knowledge type and resource modality, one could conclude that there is a general preference for the video modality in web search scenarios. Considering contextual factors like the degree to which the display of spatiotemporal changes is relevant for a knowledge type (cf. Ploetzner et al., 2020) allows for a more comprehensive understanding of selection preferences, revealing a consistent selection pattern: Tasks for which the display of spatiotemporal changes can be considered relevant lead to a preference for videos. In contrast, websites and videos are equally selected for tasks for which the display of spatiotemporal change is not considered relevant. Findings that learning with online videos is becoming increasingly popular (Feierabend et al., 2021; Koch & Beisch, 2020) should therefore be further investigated under consideration of the knowledge type of the learning task at hand.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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ENDNOTES

[1] In addition to the three hypotheses described in the present article, explicit contrasts for (H3) and a further hypothesis (H4) dealing with the interaction between modality and images were preregistered, which, however, are beyond the scope of the presented article.

[2] An exploratory model for the knowledge type CP was calculated which included prior knowledge as a factor. The main effect was insignificant and did not influence the results reported in the study.

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APPENDIX

TABLE A1 Contextual and resource factors manipulated within the study and corresponding research questions.

	Factors/levels	Investigated effects on search result selection
Contextual	Knowledge type (within-subject) Sensorimotor procedural (SP) Cognitive procedural (CP) Relational conceptual (RC) Causal Conceptual (CC)	Is there an interaction between the contextual factor of knowledge type and the resource factor of resource modality on the indicated likelihood of selecting a search result?
Resource	Resource modality (within-subject) Video Website	
	Source reputation (within-subject) High Low	Is there an interaction between the resource factors of resource modality and source reputation on the indicated likelihood of selecting a search result?
	Presentation of images (between-subject) With image Without image	Does the image presentation affect the likelihood of selecting a video or website search result?

TABLE A2 Learning tasks and sources presented for sensorimotor procedural (SP) and cognitive procedural (CP) knowledge.

Knowledge type	Learning task	Source	Source reputation High/low	M	SD
Sensorimotor procedural					
SP1	How to draw a pentagon with the help of a compass. [Wie man mit Hilfe eines Zirkels ein Fünfeck zeichnet]	Institute for Geometry TU Graz [Institut für Geometrie TU Graz]	High	6.44	0.82
		Geometry Pope [Geometriepapst]	Low	2.96	1.46
SP2	How to tie a double figure-eight knot. [Wie man einen doppelten Achterknoten bindet]	German Alpine Association [Deutscher Alpenverein]	High	6.36	0.86
		The climbing monkey [Der Kletteraffe]	Low	3.24	1.71
SP3	How to apply a pressure bandage to the hand. [Wie man einen Druckverband an der Hand anlegt]	German Red Cross [Deutsches Rotes Kreuz]	High	6.88	0.33
		Medi-Help Online [Medi-Hilfe Online]	Low	4.16	1.40
SP4	How to replace the display of the iPhone X. [Wie man beim iPhone X das Display austauscht]	Apple Support	High	5.80	1.78
		Fix-it Online	Low	3.32	1.52
Cognitive procedural					
CP1	How to calculate the electrical resistance in a parallel circuit. [wie man den elektrischen Widerstand in einer Parallelschaltung berechnet]	Society for Electrical Engineering [Gesellschaft für Elektrotechnik]	High	6.24	0.88
		The Electric Practice King [Der Elektro Übungskönig]	Low	2.64	1.29
CP2	How to calculate the volume of a prism. [wie man das Volumen eines Prismas berechnet]	Association of Mathematicians [Mathematiker-Vereinigung]	High	6.28	1.10
		Totally math—The Checker Academy [Mathetotal—Die Checker-Akademie]	Low	3.64	1.63
CP3	How to calculate the magnetic field strength of a cylindrical coil. [wie man die magnetische Feldstärke einer Zylinderspule berechnet]	Applied Sciences University Karlsruhe—Electrical Engineering Tutorials [FH Karlsruhe—Elektrotechnik Tutorials]	High	6.56	0.51
		Magnetically explained—The Physics Guys [Magnetisch erklärt—Die Physik Guys]	Low	3.80	1.44
CP4	How to calculate the probability in an urn problem with replacement. [wie man die Wahrscheinlichkeit bei einem Urnenmodell mit Zurücklegen berechnet]	Mathematics Student Council University of Ulm [Fachschaft Mathematik Uni Ulm]	High	6.40	0.87
		123-Maths—Maths Online [123-Mathe—Mathe Online]	Low	3.80	1.63

Note: *M* and SD of the source reputation refer to a material test in which 25 university students were asked to rate the reputation on a scale from 1 (very low) to 7 (very high).

TABLE A3 Learning tasks and sources presented for causal conceptual (CC) and relational conceptual (RC) knowledge.

Knowledge type	Learning task	Source	Source reputation High/low	*M*	SD
Causal conceptual					
CC1	How a drum brake works. [wie eine Trommelbremse funktioniert]	Central Association of Motor Vehicles [Zentralverband Kfz]	High	6.40	0.58
		The Internet CarHelper [Der Internet CarHelper]	Low	3.08	1.85
CC2	How thunderstorms form. [wie ein Gewitter entsteht]	German Weather Service [Deutscher Wetterdienst]	High	6.56	0.77
		The Weather Shaman [Der Wetterschamane]	Low	3.56	1.47
CC3	How an earthquake occurs. [wie ein Erdbeben entsteht]	German Research Centre for Geosciences [Deutsches Geoforschungszentrum]	High	6.72	0.54
		The plate tectonicist [Der Plattentektoniker]	Low	3.52	1.69
CC4	How a wind turbine works. [wie eine Windkraftanlage funktioniert]	Federal Wind Energy Association [Bundesverband WindEnergie]	High	6.28	1.21
		Wind energy to the power of three [Windenergie hoch drei]	Low	3.16	1.34
Relational conceptual					
RC1	How weather and climate are related. [wie Wetter und Klima zusammenhängen]	Institute for Meteorology [Institut für Meteorologie]	High	6.68	0.56
		Climate-tastic explanations [Klima-tastische Erklärungen]	Low	2.84	1.46
RC2	How pulse and blood pressure are related. [wie wie Puls und Blutdruck zusammenhängen]	Professional Association of Cardiology Specialists [Berufsverband Fachärzte Kardiologie]	High	6.68	0.63
		Cardio Heartbeat [Kardio-Herzschlag]	Low	3.80	1.29
RC3	What the relationship is between rabbits and hares. [wie der Verwandtschaftsgrad von Hasen und Kaninchen ist]	Association of species identification [Verband der Artenbestimmung]	High	6.28	0.84
		The Rabbit Hutch World Online [Die Kaninchenstallwelt Online]	Low	3.64	1.89
RC4	How alternating and direct current differ [wie sich Wechselstrom und Gleichstrom unterscheiden]	Electrical Engineering University of Vienna [Elektrotechnik Uni Wien]	High	6.68	0.62
		The Energy Knowledge [Das Energiewissen]	Low	3.60	1.44

Note: *M* and SD of the source reputation refer to a material test in which 25 university students were asked to rate the source reputation on a scale from 1 (very low) to 7 (very high).

TABLE A4 Mean (with SD) of the likelihood of selection for the two modalities depending on the factors of image and source reputation.

	With-image				Without-image			
	Low Source reputation		High Source reputation		Low Source reputation		High Source reputation	
Knowledge type	Video	Website	Video	Website	Video	Website	Video	Website
Sensorimotor procedural (SP)	5.92 (1.13)	4.57 (1.31)	6.16 (0.93)	4.97 (1.51)	5.77 (1.14)	4.65 (1.37)	6.24 (0.89)	5.25 (1.42)
Cognitive conceptual (CP)	5.19 (1.41)	5.09 (1.18)	5.41 (1.35)	5.30 (1.26)	4.87 (1.56)	4.81 (1.32)	5.13 (1.43)	5.44 (1.34)
Causal procedural (CC)	5.56 (1.23)	4.68 (1.36)	5.94 (1.01)	5.30 (1.20)	5.12 (1.33)	4.77 (1.36)	5.97 (0.93)	5.67 (1.24)
Relational conceptual (RC)	5.20 (1.36)	5.00 (1.24)	5.50 (1.28)	5.40 (1.14)	5.01 (1.29)	4.99 (1.23)	5.64 (1.11)	5.74 (1.20)