Adaptive Instruction for Elementary School Children: The Interplay of Giftedness, Working Memory, and Hypermedia Learning

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ABSTRACT

Several studies have shown that promotion offers for gifted students have positive effects on the students' educational achievement and development (e.g., Wai, Lubinski, Benbow, & Steiger, 2010). However, it is not entirely clear which promotion offers actually work best for gifted children. According to *aptitude-treatment interaction* (ATI) research (Cronbach & Snow, 1977), promotion or learning offers that are matched to a learner's specific prerequisites are assumed to be most beneficial. In line with this, promotion offers that take advantage of the specific aptitudes of gifted children should be most effective for this ability group. Unfortunately, however, studies that focus on the particular aptitudes of gifted children in order to develop appropriate learning offers are rare. Therefore, the present dissertation aimed at closing this research gap by not only exploring the specific learner characteristics of gifted children, but also by investigating whether learning offers that are designed based on the particular strengths of these children might be more beneficial than other, more common learning offers. More precisely, it was first investigated whether the construct of working memory (WM; Baddeley, 2002) represents a crucial cognitive characteristic in gifted children, even beyond intelligence. Second, it was explored whether learning offers that capitalize on the students' high WM resources, such as hypermedia environments, would be more beneficial for these students than learning offers that require lower WM resources. To this end, the present dissertation focused on the students' learning performance as well as on their navigational processing during hypermedia exploration. In total, three empirical studies, which will be outlined in the following, were conducted within the present dissertation.

Study 1 investigated whether WM capacity represents a crucial characteristic of gifted children, even beyond intelligence. For that purpose, a group of N = 42 fourth-graders, who had been nominated as gifted by their teachers, was compared with a group of N = 39 fourth-graders, who had not been nominated as being gifted, in terms of their WM capacity and their fluid intelligence. Additionally, we assessed the children's short-term memory (STM) capacity in order to rule out the possibility that simple storage functions instead of executive control functions discriminate between teacher-nominated gifted children and other children. Results showed that teacher-nominated gifted children had a significantly higher WM capacity than non-nominated children. By contrast and as expected, both groups did not differ with regard to their STM capacity. Importantly, it was demonstrated that WM was as important as intelligence in characterizing teacher-nominated gifted children, leading to the conclusion that WM capacity seems to be a crucial characteristic of these children.

Study 2 explored whether WM capacity represents a crucial learning prerequisite for achieving (complex) learning goals in a multiperspective hypermedia environment. To this end, the performance of $N = 97$ fourth-graders working through a multiperspective hypermedia environment was compared with the performance of $N = 89$ fourth-graders working through a linear learning environment as a function of their WM capacity. While working through the learning environments, the children had to deal with simple exploration tasks as well as with complex exploration tasks. It was found that children high in WM capacity performed better in the multiperspective hypermedia environment than in the linear learning environment when working on the simple exploration tasks. Contrary to this, they performed better in the linear learning environment than in the multiperspective hypermedia environment when working on the complex exploration tasks. Furthermore and most importantly, results showed that children high in WM capacity benefitted more from the multiperspective hypermedia environment than from the linear learning environment in terms of their multiperspective reasoning performance, which was assessed after learning. Children low in WM capacity, by contrast, never benefitted more from the multiperspective hypermedia environment than from the linear learning environment.

Study 3 focused on the role of navigational processes when exploring a multiperspective hypermedia environment. Specifically, the interplay of navigational behaviors, WM capacity, and performance was investigated in the 97 fourth-graders who had worked through the multiperspective hypermedia environment in Study 2. Two important navigational behaviors could be distinguished: perspective processing (i.e., navigational behavior that primarily aims to select conceptual overview pages) and irrelevant processing (i.e., navigational behaviors that do not address a given learning task). Results demonstrated that WM capacity was positively associated with the navigational behavior of perspective processing and negatively associated with irrelevant processing. Furthermore, perspective processing turned out to significantly predict learning performance. Additionally, mediation analyses revealed that perspective processing partially mediated the relation between WM capacity and learning performance.

In the General Discussion, the findings of the three empirical studies are summarized in detail and critically interpreted. Moreover, implications for future research and educational practice are derived and discussed.

ZUSAMMENFASSUNG

Die Wirksamkeit von Angeboten für hochbegabte Kinder zur Förderung ihrer schulischen Leistung und kognitiven Entwicklung konnte bereits mehrfach gezeigt werden (z.B. Wai, Lubinski, Benbow, & Steiger, 2010). Allerdings ist bisher unklar, welche Förderangebote für diese Zielgruppe am effektivsten sind. Basierend auf dem *Aptitude-Treatment Interaction* Ansatz (Cronbach & Snow, 1977) sind generell solche Förder- oder Lernangebote am effektivsten, die auf die spezifischen Fähigkeiten einer Person abgestimmt sind; im vorliegenden Fall also auf die spezifischen Fähigkeiten von Hochbegabten. Leider gibt es bislang kaum Studien, die basierend auf den spezifischen Lernvoraussetzungen bzw. Fähigkeiten von hochbegabten Kindern adäquate Lernangebote entwickelt haben. Aus diesem Grund war das Ziel der vorliegenden Dissertation sich genau mit dieser Forschungslücke zu beschäftigen. Neben der Untersuchung und Feststellung der spezifischen Lernvoraussetzungen von hochbegabten Kindern sollte auch die Effektivität von entsprechenden Lernangeboten, die auf diese Voraussetzungen angepasst sind, überprüft werden. So wurde konkret untersucht, ob das Arbeitsgedächtnis (Baddeley, 2002) neben der Intelligenz eine essentielle kognitive Charakteristik von hochbegabten Kindern darstellt. Weiterhin wurde untersucht, ob Lernangebote, die das Arbeitsgedächtnis besonders beanspruchen, so wie zum Beispiel Hypermedia Lernumgebungen, zur kognitiven Förderung von Kindern mit entsprechend hohen Arbeitsgedächtnisressourcen geeigneter sind als Lernangebote mit geringerer Beanspruchung des Arbeitsgedächtnisses. Zur Beurteilung der Effektivität wurden Lern- und Leistungsmaße sowie das Navigationsverhalten der Kinder beim Explorieren der Hypermedia Lernumgebung herangezogen. Insgesamt wurden im Rahmen der vorliegenden Dissertation drei empirische Studien durchgeführt, die im Folgenden kurz dargestellt werden.

In *Studie 1* wurde untersucht, ob Arbeitsgedächtniskapazität über Intelligenz hinaus tatsächlich eine bedeutungsvolle kognitive Charakteristik von hochbegabten Kindern darstellt. Als Kriterium für Hochbegabung wurde die Nominierung bzw. Nicht-Nominierung von Schüler/innen zu speziellen Hochbegabungskursen durch die Klassenlehrkraft herangezogen. So wurden N = 42 Viertklässler/innen, die von ihrer Lehrkraft als hochbegabt nominiert wurden, mit N = 39 nicht nominierten Viertklässler/innen hinsichtlich ihrer Arbeitsgedächtniskapazität und ihrer fluiden Intelligenz verglichen. Zusätzlich wurde die Kurzzeitgedächtniskapazität der Kinder erfasst um auszuschließen, dass sich die als hochbegabt nominierten Kinder lediglich in einfachen Speicherfunktionen statt in exekutiven Kontrollfunktionen von den nicht nominierten Kindern unterscheiden. Die Ergebnisse von

Studie 1 zeigten, dass die von Lehrern als hochbegabt nominierten Kinder eine signifikant höhere Arbeitsgedächtniskapazität hatten als die nicht nominierten Kinder. Entsprechend der Erwartungen wiesen jedoch beide Gruppen eine ähnliche Kurzzeitgedächtniskapazität auf. Weiterhin konnte gezeigt werden, dass Arbeitsgedächtniskapazität eine über Intelligenz hinaus bedeutsame Charakteristik für die von Lehrern als hochbegabt nominierten Kinder darstellt.

In *Studie 2* sollte nun untersucht werden, inwiefern Arbeitsgedächtniskapazität eine notwendige Lernvoraussetzung darstellt, um (komplexe) Lernziele in multiperspektivischen Hypermedia Lernumgebungen zu erreichen. Zu diesem Zweck wurde die Leistung von N = 97 Viertklässlern/innen, die eine multiperspektivische Hypermedia Lernumgebung explorierten, mit der Leistung von N = 89 Viertklässler/innen, die eine lineare Lernumgebung explorierten, in Abhängigkeit von ihrer Arbeitsgedächtniskapazität verglichen. Der Schwierigkeitsgrad der zu lösenden Aufgaben wurde variiert. Es konnte gezeigt werden, dass Kinder mit hoher Arbeitsgedächtniskapazität in einfachen Explorationsaufgaben bessere Leistungen zeigten, wenn sie sich mit der multiperspektivischen Hypermedia Lernumgebung beschäftigten als wenn sie sich mit der lineare Lernumgebung beschäftigten. Allerdings zeigten sie bei den komplexen Explorationsaufgaben eine bessere Leistung, wenn sie sich mit der linearen Lernumgebung beschäftigten als wenn sie sich mit der multiperspektivischen Hypermedia Lernumgebung beschäftigten. Weiterhin zeigten die Ergebnisse, dass die Beschäftigung mit der multiperspektivischen Hypermedia Lernumgebung das multiperspektivische Denken bei Kindern mit hoher Arbeitsgedächtniskapazität besser stimulierte als die Beschäftigung mit der linearen Lernumgebung. Hingegen profitierten Kinder mit geringer Arbeitsgedächtniskapazität für keines der Lernmaße mehr von der multiperspektivischen Hypermedia Lernumgebung als von der linearen Lernumgebung.

Der Fokus von *Studie 3* lag auf den Navigationsprozessen der 97 Viertklässler/innen, die in Studie 2 die multiperspektivische Hypermedia Lernumgebung exploriert hatten. So wurde untersucht, wie das Navigationsverhalten dieser Kinder mit ihrer Arbeitsgedächtniskapazität sowie mit ihrer Explorations- und Lernleistung zusammenhängt. Dabei konnten zwei bedeutsame Navigationsverhaltensweisen unterschieden werden: „Perspektivisches Vorgehen“ (*perspective processing*, d.h. Navigationsverhalten, das auf die Auswahl von konzeptuellen Überblicksseiten fokussiert) und „Irrelevantes Vorgehen“ (*irrelevant processing*, d.h. Navigationsverhalten, das nicht darauf ausgerichtet ist eine vorgegebene Lernaufgabe zu adressieren). Die Ergebnisse von Studie 3 zeigten, dass Arbeitsgedächtniskapazität positiv mit „Perspektivischem Vorgehen“ und negativ mit

„Irrelevantem Vorgehen“ zusammenhing. Weiterhin konnte das Perspektivische Vorgehen signifikant die Lernleistung vorhersagen. Außerdem zeigten Mediationsanalysen, dass Perspektivisches Vorgehen den Zusammenhang zwischen Arbeitsgedächtniskapazität und Lernleistung partiell mediierte.

In der allgemeinen Diskussion werden die Befunde der drei empirischen Studien detailliert zusammengefasst und kritisch begutachtet. Darüber hinaus werden Implikationen für die zukünftige Forschung sowie für die pädagogische Praxis abgeleitet und diskutiert.

CONTENT

1

Introduction and Theoretical Framework

1 Introduction and Theoretical Framework

Not every child has an equal talent or an equal ability or equal motivation, but children have the equal right to develop their talent, their ability, and their motivation.

(John F. Kennedy)

The educational system is supposed to guarantee all students equal education opportunities. With regard to a liberal interpretation of the term equal education opportunities, all students should have the chance to make the most out of themselves with the educational system providing corresponding means (cf. Heckhausen, 1981; Tomlinson, Brimijoin, & Narvaez, 2008). Such equal opportunities can be best achieved if each student is instructed based on his or her individual needs. For instance, a student with dyscalculia needs different mathematical instruction than a student without dyscalculia. The same is true for a student suffering from dyslexia concerning language instruction. In this vein, literature describes specific intervention programs that aim to compensate for students' particular learning disabilities by drawing on the students' underlying learning deficits (Kaufmann, Handl, & Thöny, 2003; Struiksma, van der Leij, & Stoel, 2009; Thomson, Leong, & Goswami, 2013). More precisely, research on dyscalculia, for instance, has shown that students with dyscalculia exhibit deficits in their visual-spatial abilities and their representation of numerosities, that is, enumerating small sets of numbers or comparing the numerosities of two quantities (Butterworth, Varma, & Laurillard, 2011; Kaufmann et al., 2003; Schuchhardt, Maehler, & Hasselhorn, 2008). Correspondingly, intervention programs that specifically support the acquisition of spatial skills and the consolidation of the numerosity system for representing and manipulating sets of numbers are likely to be most suitable (Butterworth et al., 2011; Kaufmann et al., 2003; Schuchhardt et al., 2008). Students suffering from dyslexia, by contrast, exhibit deficits in their phonological awareness so that phonology-based interventions seem most appropriate (Butterworth et al., 2011; Struiksma et al., 2009; Thomson et al., 2013). To conclude, instructions that are adapted to the student's specific deficits are most suitable. This reasoning about adapted instruction is in line with the idea of *aptitude-treatment interaction* (ATI) research (Cronbach & Snow, 1977), which states that optimal learning occurs when an instructional design is matched to learners' particular prerequisites.

Referring back to the term equal education opportunities, a mere focus on students with learning deficits is not sufficient. A consideration of students on the other side of the performance spectrum is equally important, specifically the consideration of gifted[1] students. Although these students are not supposed to exhibit specific deficits that hamper their learning processes, they should nevertheless have the chance to receive instructions that capitalize on their inherent learning prerequisites (cf. Cooper, 2009). In line with this, it has been shown that early promotion offers for gifted children such as acceleration, enrichment, or grouping have positive effects on their later achievement and academic careers (e.g., Kulik & Kulik, 1982; Robinson, Abbott, Berninger, Busse, & Mukhopadhyay, 1997; Wai, Lubinski, Benbow, & Steiger, 2010). Unfortunately, however, this high ability group is still underserved in the educational context (Borland, 2005; Chamberlin, Buchanan, & Vercimak, 2007; Robinson, 2008). Moreover, the few existing attempts to promote gifted students are heterogeneous and largely incomparable so that it is yet to discover which approach actually works best. In this vein, Wai and colleagues (2010) proposed that there are multiple ways to meet the needs of gifted students so that "It may not matter so much what they get but that they get something in a sufficient dose…" (p. 870). Contrary to this, however, Heller (1999; see also Heller, Perleth, & Lim, 2005) has claimed that for an effective education of gifted students cognitive and motivational pre-conditions of the learning process have to fit the instructional situation. According to ATI (Cronbach & Snow, 1977), the latter perspective might rather satisfy the requirements of gifted students as promotion offers that particularly take advantage of the students' strengths are likely to be most effective. In this sense, Sternberg, Ferrari, Clinkenbeard, and Grigorenko (1996) demonstrated that gifted students performed better when instructional conditions matched their patterns of ability as compared to students who received instruction that did not match their patterns of ability. In general, however, empirical studies that adequately investigated the specific learning prerequisites of gifted students in order to develop tailored promotion offers are, at best, rare. As will be argued in the following, this might be due to the fact that the specific learning prerequisites of gifted students are not easy to determine.

Various conceptions of giftedness exist in the literature, which all have different perceptions of what characteristics or learning prerequisites might be inherent in gifted students (Sternberg & Davidson, 2005; Subotnik & Thompson, 2010). As a consequence,

[1] As will be argued in the present dissertation, the term *gifted* is not precisely defined in the literature as various definitions of giftedness exist (e.g., Sternberg & Davidson, 2005). Thus, – at the current state of research –gifted students can be described as high IQ students, high achieving students, highly creative students, highly motivated students, or by any other ability characteristic that makes them outstanding.

there is no consensus on what constitutes giftedness and, by implication, how to appropriately promote gifted students. Neither is there agreement among researchers on how to optimally identify gifted students for promotion programs. However, the selection of gifted students for gifted promotion offers is often more guided by practical than by conceptual reasons (e.g., Friedman-Nimz, 2009). In this vein, a commonly used method for deciding whether a child is gifted or not is teachers' nomination (e.g., Freeman & Josepsson, 2002; Rost & Buch, 2010). On the one hand, teachers see, interact, and assess students constantly in the educational context so that they can base their giftedness judgments on a broad range of students' characteristics (e.g., Baudson, 2010; Borland, 1978). On the other hand, however, it is not entirely clear which specific criteria underlie teachers' giftedness judgments and, in turn, which specific variables characterize these teacher-nominated gifted children. Teachers themselves indicate to consider high cognitive potential, such as high intelligence, as an important characteristic of giftedness, and hence, for their giftedness decisions (e.g., Endepohls-Ulpe & Ruf, 2005). Nevertheless, it has been found that on average students nominated as gifted by teachers do not have an exceptionally high intelligence score, that is, a score two standard deviations above the mean (e.g., Neber, 2004). Thus, there seem to be important other variables characterizing children identified as gifted by teachers. As will be argued in the present dissertation, a cognitive construct that has so far been neglected in the field of giftedness, but which is likely to represent an important learning prerequisite of children identified as gifted by teachers – even beyond intelligence – is working memory (WM; e.g., Baddeley, 2002).

Assuming that high WM capacity is an important learning characteristic of gifted students, including teacher-nominated gifted children, it is reasonable – according to ATI research – to provide learning offers that particularly take advantage of these resources (Cronbach & Snow, 1977). WM resources are associated with executive control processes such as the simultaneous processing of information, the planning and conducting of goal-directed behavior, the focus on relevant information, the inhibition of irrelevant information, and the switching between task demands (Baddeley, 2007; 2012; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Oberauer, 2009). Accordingly, learning offers that demand such executive control processes (i.e., to autonomously structure and control one's learning process) are supposed to be most promotive for these students. Specifically, on the one hand, respective learning offers may further exercise the students' particular learning prerequisites (i.e., WM resources) so that these prerequisites can be given complete expression (cf. zone of proximal development, Vygotsky, 1978). On the other hand, they may additionally better stimulate complex learning processes such as, for instance, multiperspective reasoning or inferential thinking (e.g., Zydney, 2010), than less demanding learning offers. Extending this line of reasoning, an example for appropriate learning settings for students with high WM capacity might be instructional hypermedia environments. Hypermedia environments are characterized by presenting information in a nonlinear format, such as it can be found, for instance, on the internet (Scheiter & Gerjets, 2007), and are nowadays getting increasingly important in the educational system. Apart from their high degree of executive control demands, hypermedia environments provide an innovative and interactive learning approach that implies high potential for learning as compared with traditional, simpler learning offers (e.g., Jacobson, Maouri, Mishra, & Kolar, 1996). However, whether such hypermedia environments are actually better suited for children with high WM resources than more easily structured learning offers has, to the best of my knowledge, not yet been empirically investigated.

Based on the assumption that particularly high WM capacity enables learners to benefit from hypermedia instruction, a focus on the underlying processes that might explain the positive association between WM capacity and hypermedia learning could be additionally insightful. In accordance with this train of thought, the current dissertation specifically refers to navigational processes, which have been shown to strongly influence performance in hypermedia environments (e.g., Lawless & Kulikowich, 1996). However, whether the assumed association between high WM capacity and successful hypermedia learning might be mediated by effective navigational processing has not been addressed so far. In sum, a variety of questions concerning the interplay of WM capacity, hypermedia learning, and navigational processes, thus, remain unanswered within the present state of research.

The aim of the present dissertation is twofold. First, one focus will be on the role of WM capacity in teacher-nominated gifted children, hereby exploring whether WM capacity indeed represents a crucial characteristic of these children that might even outperform the so far most accepted component of giftedness, namely fluid intelligence. Second, based on the idea of ATI (Cronbach & Snow, 1977), it will be examined whether learning offers that are matched to learners’ prerequisites (i.e., high WM resources) might be more beneficial than other, more traditional learning offers with regard to comprehension and learning. To this end, the present dissertation will delve into the interplay of WM capacity and hypermedia learning. More precisely, the influence of WM capacity for successful learning when dealing with hypermedia environments will be addressed. Moreover, assuming that WM capacity is positively associated with hypermedia learning, this dissertation further dwells on navigational processes during hypermedia learning in order to examine whether these might explain the relation between WM capacity and successful hypermedia learning.

The present dissertation comprises five chapters: the Introduction and Theoretical Framework (1), the three empirical studies (2-4), and the General Discussion (5). More specifically, the introductory chapter (1), which is aimed at embedding the three empirical studies that were herein conducted within a broader theoretical and contextual framework, is structured as follows: In the first part (1.1), the multifaceted concept of giftedness will be introduced by referring to various conceptions of giftedness. Moreover, the different identification procedures as well as promotion offers for gifted students will be outlined. Next, the practical applications of gifted selections will be introduced, thereby concluding that gifted selections by teachers are predominant in the practical context. Finally, empirical research on the specific characteristics of teacher-nominated gifted children will be reviewed with an emphasis on the so far unattended cognitive characteristic of WM, which represents the focal construct of the present dissertation. In the second part (1.2), the construct of WM will be explored in detail. First, different models conceptualizing the system of WM as well as an operational definition of WM will be illustrated. Next, the relation of WM to other cognitive constructs will be discussed. Moreover, its relevance for educational outcomes will be emphasized. Finally, the interplay of WM and giftedness will be discussed, thereby leading to the importance of appropriately tailored learning offers. In the third part of the introductory chapter (1.3), hypermedia environments, which are herein considered as such appropriate learning offers, will be introduced. Subsequently, hypermedia environments will be related to cognitive theories and the potentials and drawbacks of hypermedia environments will be pointed out. Finally, the relation between hypermedia learning and WM capacity as well as the role of navigation in hypermedia environments will be discussed in detail. The introductory chapter will conclude by introducing the research questions underlying the three empirical studies (1.4). The following three chapters (2-4) will describe the three empirical studies realized within the framework of this dissertation. In the last chapter of the present dissertation (5), the findings of the three empirical studies will be summarized and discussed (5.1). Subsequently, the strengths as well as the limitations of the three studies will be outlined (5.2), followed by a discussion of the implications for future research and educational practice (5.3). The chapter will conclude with a brief summary of the most important findings (5.4).

1.1 Giftedness

For a long time, the concept of giftedness mainly considered those students as gifted who scored about the top 3-5% of the intelligence distribution (cf. Terman, 1924; Terman & Oden, 1959). Thus, only one single measure, namely intelligence, decided about whether a student was gifted or not. Nowadays, this concept of giftedness is outdated as it is considered as a too narrow perspective (Borland, 2009; Sternberg, Jarvin, & Grigorenko, 2011). Unfortunately, however, despite several efforts, no topical, generally accepted conception of giftedness has been constituted yet. Instead, various multifaceted conceptions of giftedness have been introduced (cf. Sternberg & Davidson, 2005). Although these conceptions still consider intelligence to be one important component of giftedness, they differ with regard to four critical issues, including structural characteristics (e.g., further components) as well as boundary conditions (e.g., environmental factors), that will be specified in the following.

First, giftedness conceptions differ largely to the extent to which they consider additional personal characteristics to be fundamental for the concept of giftedness. That is to say, some researchers define further cognitive characteristics, besides intelligence, to be inherent in gifted individuals such as, for instance, creativity (e.g., Jeltova & Grigorenko, 2005). Others emphasize the important role of non-cognitive characteristics such as, for instance, achievement motivation or social competencies (e.g., Heller et al., 2005). Second, giftedness conceptions also differ to the extent to which they consider environmental factors as being important for giftedness, that is, factors beyond students' individual characteristics such as family support or classroom climate (e.g., Heller et al., 2005). Whereas some conceptions do not consider these environmental variables at all (e.g., Renzulli, 2005), others claim that an optimal (supportive) environment is necessary for giftedness to find complete expression (e.g., Heller et al., 2005). Third, conceptions differ in their view as to whether giftedness is considered as potential or achievement. Some researchers argue that giftedness is a potential that does not automatically transition into high performance (e.g., Karólyi & Winner, 2005). Others, by contrast, consider high performance as a necessary condition to justify the term giftedness (e.g., Ziegler, 2005). Fourth, giftedness conceptions differ in their opinion as to whether they see giftedness as a broad potential (e.g., Karólyi & Winner, 2005) or only as a specific potential in a certain domain area such as, for instance, mathematics (e.g., Heller et al., 2005).

Taken together, different multifaceted conceptions of giftedness, which vary in the four issues mentioned above (i.e., personal characteristics, environmental factors, potential vs. performance, broad vs. specific), coexist in the literature. In order to convey a sense of these rather diverse theories, the present dissertation will shortly present three different, but prominent giftedness conceptions below.

1.1.1 Conceptions of giftedness

As outlined above, three different giftedness conceptions with increasing complexity (i.e., 1: cognitive variables, 2: cognitive variables and personal characteristics, 3: cognitive variables, personal characteristics, environmental conditions, and performance areas) will be described starting with the componential theory of intellectual giftedness (Sternberg, 1981) as an example of a conception that only considers cognitive components. However, as current giftedness conceptions typically comprise more characteristics than intelligence (cf. Sternberg & Davidson, 2005), the componential theory of intellectual giftedness (Sternberg, 1981) might nowadays be regarded as a too narrow perspective (e.g., Subotnik, Olszewski-Kubilius, & Worrell, 2011; Worrell, 2009). Therefore, Renzulli's three-ring-conception of giftedness (1978; 1990; 2005), which includes additional personal characteristics besides cognitive ability, will be presented next. Finally, an example of an influential conception of giftedness that additionally includes environmental factors and various performance areas, namely the Munich model of giftedness (Heller, et al., 2005), will be given. For a comparative overview of the three models see also Table 1.

The componential theory of intellectual giftedness

The componential theory of intellectual giftedness (Sternberg, 1981; see also VanTassel-Baska & Brown, 2007) does not explicitly characterize attributes of gifted students but rather describes the underlying differences in their mental structures and processes that differentiate them from other students. Sternberg, thus, defines giftedness in terms of an information-processing theory and not in terms of a psychometric construct. According to his theory, the superior functioning of three information-processing components, namely of metacomponents, of performance components, as well as of acquisition, retention, and transfer components, makes up intellectual giftedness.

Metacomponents represent higher-order control processes and are thus the central elements of the information-processing system. More specifically, they are responsible for executive planning and decision making during problem solving. This includes the recognition of a problem, the effective organization of possible solution steps, and the application of appropriate strategies to solve the problem. Moreover, metacomponents are responsible for building up representations of the problem that might later be useful for effective problem solving. Further, the optimal allocation of one's resources and the permanent monitoring and consequently flexible adjustment of the problem solving process can also be ascribed to the functioning of the metacomponents.

Performance components, by contrast, are responsible for the execution of a problem-solving strategy. This is defined, for instance, by detecting relations between two objects in a given domain (inference) or relating an aspect from one domain to a second one (mapping) in order to make predictions about the second domain (application). Moreover, comparing the generated predictions to alternative options (comparison) and checking for the validity of these options (justification) should finally result in communicating a solution (response). Sternberg assumes only gifted students to be particularly successful and quick in executing these performance components.

Lastly, acquisition components are assumed to be involved in learning new information, retention components are assumed to be involved in retrieving previously acquired information, and transfer components are assumed to be involved during the generalization of maintained information to a novel context.

Although all components are supposed to be highly interactive during information-processing, the metacomponents have the most important role as they are always the initial source and final deposition of all processed information. Importantly, gifted students are not only supposed to show a generally superior functioning of all single components but also to have highly qualitative and quantitative interactions among these. According to Sternberg and Clinkenbeard (1995), the different components described above can be subsumed under the term memory-analytic abilities and are typically assessed with items from standardized tests of intelligence, such as verbal analogies, number series, or matrix completion. However, a mere consideration and assessment of high-level cognitive abilities associated with fluid intelligence (e.g., inductive reasoning or making analogies) can hardly satisfy the multifaceted functions of the components described by Sternberg (1981). That is to say, these components also seem to comprise lower-level cognitive functions, such as executive control (e.g., planning and monitoring) and storing (e.g., acquiring and retaining knowledge). These lower-level cognitive functions, however, can rather be ascribed to the system of working memory (e.g., Baddeley, 2002) and may thus not be appropriately assessed with ordinary intelligence items. A more detailed description of working memory functions will follow later (see 1.2).

The three-ring-conception of giftedness

The three-ring-conception of giftedness by Renzulli (1990; 2005) is arguably one of the most well-known giftedness conceptions. According to Renzulli, two kinds of giftedness can be differentiated, namely the schoolhouse giftedness and the creative-productive giftedness. The schoolhouse giftedness is manifested in school achievement such as excellent grades and test scores. As this kind of giftedness is mostly visible to teachers, it mainly applies to pupils. Although high IQ plays an important role for schoolhouse giftedness, its mere availability is not sufficient. Instead, high intelligence as well as high task-commitment and a substantial degree of creativity have to come together. According to Renzulli, a student is only identified by the school as gifted if the available intellectual potential is also realized in performance. Creative-productive giftedness, by contrast, is rather shown by adults who stand out by developing original products that have an impact on society such as, for instance, writing books, composing music, or creating innovative techniques. Whereas this kind of giftedness can also be found among children, the schoolhouse giftedness can rarely be applied to adults whose grades or test scores are usually not assessed any more.

According to Renzulli, the two kinds of giftedness are hardly overlapping so that it is likely that people are not identified as gifted in school but may later convince others of their creative-productive giftedness. The same is true for children who have been identified as gifted in school but later do not stand out with creative, original products. The factors that mainly constitute creative-productive giftedness (as well as schoolhouse giftedness), namely above average ability, task commitment, and creativity, make up the three-ring-conception. Recently, Renzulli (2005) extended his three-ring-conception by adding broader traits (e.g., optimism, courage, etc.) as well as general and specific performance areas (e.g., mathematics or statistics) that are supposed to give rise to the three ring factors. He refers to this extension as Houndstooth background (Renzulli, 2005).

In an early study, Reis and Renzulli (1982) attempted to demonstrate that above-average ability is not sufficient to determine giftedness. To this end, they compared a group of students who scored in the top 5% on a standardized intelligence test with a group of students who scored from 10 to 15 percentile points below the top 5%. All students took part in a course program for gifted students and had to create products. The quality of these products was rated on the basis of several qualitative characteristics by expert judges who were blind to the hypotheses. Results revealed that both groups did not differ significantly with respect to the quality of their products indicating that the expression of giftedness is not limited to the traditional top 5% most intelligent students but that additionally other components, namely task-commitment and creativity, might be important. Disadvantageously, the three-ring-conception only considers those children as gifted who are sufficiently motivated and show high performance. Children with high intelligence but who are not motivated and show poor performance (i.e., underachievers) “fall through the cracks” and receive no promotion.

The multifactorial Munich model of giftedness

The multifactorial Munich model of giftedness by Heller and colleagues (2005) defines giftedness as a network of intrapersonal talent factors as predictors (e.g., intellectual abilities, creative abilities, social competence) and various performance areas as criteria (e.g., mathematics, natural sciences, technology). Moreover, the model also includes non-cognitive personality characteristics (e.g., coping with stress, achievement motivation) and environmental conditions (e.g., family learning environment, quality of instruction) that represent moderators to convey the potential talents into excellent performance. By integrating so many cognitive, non-cognitive, and environmental factors as well as several performance-related variables, the model represents a very vague and somehow unspecific conception of giftedness. Nevertheless, it provides a framework that allows for testing various interdependencies between the different factors and moderators. In this vein, Perleth and Heller (1994) attempted to validate the Munich model of giftedness in a longitudinal study taking place from 1985 to 1989. In this study all factors inherent to the model were assessed: Five giftedness domains (intellectual, creative, social, practical, artistic), different performance areas (e.g., sports, sciences, arts), noncognitive personality traits (e.g., coping with stress, achievement motivation), and environmental conditions (family, school climate, critical life events). The results revealed that the five giftedness domains (or talent factors, respectively) represented independent dimensions. Highly gifted students in one of the five domains significantly differed from average students (i.e., students not gifted in this specific domain) in several aspects. For instance, the intellectually gifted differed in their school grades from average students, and the creative gifted differed in their artistic success from average students. Moreover, the authors found noncognitive personality traits, namely motivational characteristics, to play a mediating role. Unfortunately, the results of cluster analyses did not support the establishment of a clear typology of giftedness. Taken together, as not all possible relations and interdependencies of the variables within the model have yet been addressed, the validation of the entire model can still not be concluded.

To conclude, there is currently no uniformly accepted definition of giftedness. Instead, different, multifaceted models exist that strongly vary with regard to their giftedness conceptualization (e.g., additional personal characteristics or environmental conditions). Moreover, there is, unfortunately, still insufficient research that has empirically examined the various giftedness models so that it is not expedient to exclusively refer to one specific giftedness conceptualization in order to define giftedness. Rather, it is advisable to focus on giftedness factors that are most generally accepted among various conceptions. In this sense, the lowest common denominator of all giftedness conceptions seems to be the cognitive component. More specifically, all giftedness conceptions consider – at least to some degree – high cognitive potential as an important component of giftedness (Sternberg et al., 2011). Thus, when defining giftedness, a primary focus on high cognitive potential seems to be most reasonable – at least from the viewpoint of the present dissertation. Nevertheless, giftedness is not only a theoretical issue but, importantly, also a methodological matter, including the identification as well as the promotion of gifted students. Therefore, the present dissertation will subsequently dwell on gifted identification procedures (1.1.2) as well as on gifted promotion offers (1.1.3).

Table 1

Description of the Three Conceptions of Giftedness on the Basis of (1) Personal Characteristics, (2) Environmental Factors, (3) Potential vs. Achievement, and (4) Broad or Specific Potential

Conceptions of giftedness	*(1) Personal factors*	*(2) Environmental factors*	*(3) Potential vs. achievement*	*(4) Broad vs. specific*
The componential theory of intellectual giftedness (Sternberg, 1981)	Information-processing components (metacomponents, performance components, acquisition, retention, and transfer components)	The environment has to provide trainings to facilitate access and implementation of these components → only then individuals can become “more intelligent” or “truly gifted”	Potential: giftedness is defined as high cognitive functioning	Broad cognitive potential
The three-ring-conception of giftedness (Renzulli, 2005)	Above-average ability, task-commitment, and creativity	None	Intellectual/creative potential has to be realized in performance (i.e., achievement)	Specific: Giftedness can find expression in different performance areas (e.g., chemistry, ballet, sculpture)
The multifactorial Munich model of Giftedness (Heller et al., 2005)	Intrapersonal talent factors (e.g., intellectual ability, creative abilities), non-cognitive personality characteristics (e.g., coping with stress, achievement motivation)	Family climate, classroom climate, critical life events	Potential is reflected by intrapersonal talent factors; achievement by performance areas	Specific: various performance areas (e.g., mathematics, natural sciences, technology)

1.1.2 Identification of gifted students

As with the various giftedness conceptions, several procedures to identify the gifted exist in the literature. Given that the identification of gifted students is always based on specific reasons (e.g., selection for promotion programs or for a gifted research study), the proper selection of respective identification procedures is very important. For instance, when identifying gifted students for specific promotion programs, the selection of identification procedures should be carefully based on the learning goals of the corresponding promotion program (Steinheider, 2014; Vock, Preckel, & Holling, 2007). However, before further dwelling on this issue (i.e., proper selection of identification procedures), the most commonly used identification measures will be described.

Standardized intelligence tests are a widespread procedure to identify gifted students (cf. Bergold, 2011). Intelligence tests allow for (relatively) objective, reliable, and valid IQ score assessments. Thereby, the tested student cannot only be compared to other students but also to a normed reference score, which reveals whether the student's ability ranges in the top level of the intelligence distribution. Accordingly, when students score high on the intelligence measure, they may be labeled as gifted, however, only on condition that high intelligence represents an exclusive criterion for giftedness. As already mentioned above, it has been criticized for years to consider only intelligence for describing and also identifying gifted students (e.g., Subotnik et al., 2011; Worrell, 2009). Therefore, intelligence tests do not represent a sufficient identification measure for many giftedness researchers (e.g., Subotnik et al., 2011). Moreover, these tests only measure intellectual potential but do not guarantee outstanding performance, which is, however, considered as important in several giftedness conceptions (e.g., Heller et al., 2005).

Another commonly used method in the gifted identification process, particularly in the United States, is the application of standardized achievement tests (Sternberg et al., 2011). These tests assess achievement in multiple academic subjects such as, for example, reading comprehension, mathematical concepts, or biological knowledge (cf. Scholastic Aptitute Test, SAT) and are scored according to uniform procedures. Although they validly and reliably assess the achievement potential of a student, they do not disclose his or her true intellectual potential, which still reflects the most commonly accepted component of giftedness (e.g., Sternberg et al., 2011). In this vein, for instance, Pirozzo (1982) claims that about half of the children who score in the top 5% of an intelligence test do not show an equally high school achievement. Consequently, when using standardized achievement tests, these children are less likely to be identified as gifted. This is especially the case for gifted underachievers who exhibit a great discrepancy between potential (or ability) and performance (or achievement) (Reis & McCoach, 2000).

Another widespread identification procedure is teacher's nomination, that is, teachers select those children in their class that they perceive to be most gifted (Borthwick, Dow, Levesque, & Banks, 1980; Hodge & Cutmore, 1986; Neber, 2004; Rost & Buch, 2010). Particularly with regard to gifted selections for promotion programs, teachers' giftedness screenings play a major role (McBee, 2006; Rost, Sparfeldt, & Schilling, 2006; Siegle & Powell, 2004). This is not surprising as teachers' nominations yield several advantages. From a practical perspective, for instance, teachers' nominations are comparatively economical with respect to organizational issues. Importantly, teachers also see, interact, and assess students consistently, so that they observe a broad range of students' characteristics over time and in various situations (Borland, 1978; Jarosewich, Pfeiffer, & Morris, 2002; Siegle, 2001). Moreover, due to their extensive experience with various students, teachers are able to compare among students which gives them a point of reference about who is average and who might be gifted (Baudson, 2010). Particularly elementary school teachers, who can typically assess a student in more than one subject, may recognize a variety of crucial characteristics that discriminate gifted students from other students (Endepohls-Ulpe & Ruf, 2005). Early empirical studies demonstrated that teachers' nominations did not exactly select those children as gifted who might have been selected with an intelligence testing (Terman, 1924; Gear, 1976; Pegnato & Birch, 1959). Specifically, in his comprehensive review, Gear (1976) reported that teachers only nominated 30-40% of the students who scored high on an intelligence measure as gifted and nominated about 50% of the students as gifted who did not score high on an intelligence measure. In a more recent study by Neber (2004), it was demonstrated that teachers identified all children as gifted who also scored high on a cognitive ability test. By contrast, teachers still nominated too many students as gifted who did not score high on a cognitive ability test (about 80%). Nevertheless, although teachers might not be able to estimate intelligence test scores one-to-one, correlations between teacher ratings and intelligence tests are substantial (cf. Egan & Archer, 1985; Hodge & Cudmore, 1986; McBee, 2006; Wild, 1993). In this vein, for instance, Wild (1993) reported teachers' estimations of a student's intelligence and the student's true intelligence score to correlate between r = 0.4 and r = 0.59. In a study by Kirk (1966) among preschool children respective correlations were even found to amount up to r = .73. Moreover, as already stated above, current researchers in the field of giftedness criticize the consideration of intelligence as an exclusive criterion for giftedness (e.g., Subotnik et al., 2011) implying that not too much emphasis should be put on the association between teacher judgments and IQ scores. Instead, recent research claims teachers to be a quite reliable source for gifted identification and recommends teacher nominations to be integrated in the gifted identification process (Gagné, 1994; McBee, 2006; Robinson, Shore, & Enersen, 2007; Worrell & Schaefer, 2004).

Furthermore, as the component of creativity plays a crucial role in several giftedness conceptions (e.g., Mönks & Katzko, 2005; Renzulli, 2005), the application of creativity tests is not unusual when identifying gifted students. Hunsaker and Callahan (1995) reported that among 418 school districts in the United States 69.6% included the term creativity in their definition of giftedness. However, only 34.7% of those school districts who included the term creativity actually applied creativity measures during gifted identification. This might be due to the fact that the construct of creativity is only vaguely defined and has been shown to be slightly unreliable (Sparfeldt, Wirthwein, & Rost, 2009). More specifically, Sparfeldt and colleagues (2009) reported a stability coefficient of only $r = .33$ for a creativity measure in the course of a longitudinal giftedness study (Marburger Hochbegabtenprojekt, Rost, 1993). Rost (2009) attributed this low reliability to the instability of creativity during adolescence and suggested not to take it as a crucial indicator of giftedness.

Finally, further identification methods such as nominations by parents, peers, and the gifted student him- or herself exist (e.g., Renzulli, 2005). However, these identification procedures have to be critically considered. For instance, with regard to gifted nominations by the students themselves, Neber (2004) criticized that students have a strong tendency to overestimate their own abilities. More precisely, in his study more than 80% of the students considered themselves to be highly gifted although they did not exhibit correspondingly high abilities. Moreover, Lee and Olszewski-Kubiliu (2006) investigated the effectiveness of parents' gifted nominations. They reported that children who had been nominated by their parents to take part in a talent search testing showed lower performance in various achievement tests than children who had been identified by standardized tests ($d = .10 – .31$). Taken together, these identification methods have demonstrated relatively low validity and are therefore rarely applied (e.g., Perleth, Preckel, Denstädt, & Leithner, 2008; Schroth, Helfer, & College, 2008; Wild, 1991).

Considering the variety of identification procedures and approaches, it becomes obvious that there is no state-of-the-art solution for identifying the gifted. In this vein, Carman (2013) compared the identification procedures among 104 research studies. She found a wide variability of used methods with the most commonly used method being prior identification by the schools (reported in more than three quarters of the studies). About 10.7% of these studies did not further specify this prior identification. Concerning the other studies, 62% reported having used an intelligence measure, 34.8% reported having used an achievement test, and 22.8% reported having used teacher recommendations. Carman (2013) critically stated that the variety of operationalizations when selecting gifted individuals for research studies leads to lower generalizability of the results and to an inability for researchers in the field to compare the results of different studies (see also Zettler, Thoemmes, Hasselhorn, & Trautwein, 2014). However, based on the general disagreement about the conceptualization of giftedness (e.g., Sternberg & Davidson, 2005), several giftedness researchers state that there is no single “silver bullet” in identification (Callahan, 2009; Friedman-Nimz, 2009; Worrell, 2009). They agree, however, on the theoretical necessity of multidimensional assessments (Borland, 2008; Friedman-Nimz, 2009; Heller et al., 2005; Mönks & Katzko, 2005). Most importantly and as already mentioned above, the selection of the identification procedures should be carefully based on the specific learning goals of the corresponding promotion program (Steinheider, 2014; Vock et al., 2007). More precisely, if a promotion program aims to support children’s inventive mind by stimulating them, for instance, to generate creative products, identification procedures should amongst others include a creativity measure. Otherwise, unsuitable children (i.e., not creative at all) might attend these promotion offers but might not be able to actually benefit from them (cf. Zettler et al., 2014). Consequently, the whole promotion project would be foredoomed to fail. This reasoning is in line with the idea of ATI (Cronbach & Snow, 1977) in that learners and learning offers have to be appropriately matched. In the following, the various promotion offers for gifted students will be illustrated in more detail.

1.1.3 Promotion offers for gifted students

Many approaches to promote the gifted have already been undertaken. In general, these approaches can be differentiated into external and internal differentiation measures. Specifically, whereas external differentiation measures refer to educational programs that separate gifted children from their classmates, internal differentiation concerns distinct instructional methods for the gifted in a heterogeneous classroom (Heller, 1999). With regard to external differentiation, three main approaches of gifted interventions can be distinguished, namely (a) acceleration, (b) enrichment, and (c) grouping (e.g., Hagmann-von-Arx, Meyer, & Grob, 2008). Although these approaches may be intertwined with each other, they can still be distinctively described.

First, acceleration refers to strategies that allow students to pass faster through the regular school system than their schoolmates. These acceleration strategies include early entrance into school, grade skipping, and visiting college courses while still being in high-school (i.e., advanced placement). In a recent meta-analysis, Steenbergen-Hu and Moon (2011) reported acceleration to positively affect academic achievement and, to a lesser extent, social-emotional development.

Second, enrichment refers to additional learning offers for the gifted besides the regular curriculum. Thereby, a differentiation between vertical and horizontal enrichment can be made (Nogueira, 2006): Vertical enrichment offers aim at intensifying a certain topic such as, for instance, geometry by providing specific lessons. Horizontal enrichment offers, by contrast, aim at providing additional subject matters such as, for instance, learning a new language. Generally, these enrichment offers take place outside of school time (e.g., in the afternoon or during the holidays). However, it is also possible that these enrichment offers take place during school lessons. They are then referred to as pull-out-programs. In her comprehensive review about educational practice among gifted and talented, Rogers (2007) concluded enrichment offers to be less compelling than acceleration measures. However, in combination with acceleration, enrichment offers seem to be very beneficial for the gifted. Vaughn, Feldhusen, and Asher (1991) explicitly reviewed the effectiveness of pull-out programs and found small to medium positive effects in the areas of academic achievement as well as of critical and creative thinking. They thus concluded pull-out-programs to benefit gifted learners.

Third, grouping or ability grouping refers to the separation of gifted students from their average peers into homogenous learner groups. There are several levels of grouping: multilevel classes (i.e., all students in the same grade are divided into different ability groups), cross-grade grouping (i.e., students from several grades are formed into groups based on their achievement), within-class grouping (i.e., students in the same class are divided into different ability groups), or entire schools for the gifted (cf. Kulik & Kulik, 1992). Furthermore, a differentiation can be made between enriched classes, in which gifted students are grouped to receive richer educational experience, and accelerated classes, in which gifted students are grouped to receive instructions that allow them to proceed faster through the learning materials. Meta-analyses by Kulik and Kulik (1992; 2004) revealed multilevel classes to have no or only little effects on students' achievement. Cross-grade grouping and within-class grouping, by contrast, were associated with positive effects on achievement. However, enriched and accelerated classes for the gifted appeared to have the strongest impact on achievement.

As already mentioned above, the three approaches are strongly overlapping as they all provide gifted students with learning materials beyond the curriculum. Therefore, investigations to test the differential effectiveness of these approaches can hardly be conducted nor can their results be appropriately evaluated. In this vein, for instance, Wai and colleagues (2010) longitudinally investigated the general benefit of early promotion offers on gifted students' later success and achievement. More precisely, instead of distinguishing between the types of intervention approach, the authors counted all accelerating as well as enriching opportunities that aimed at cognitively stimulating the gifted as equally appropriate promotion offers for their study. Wai et al. (2010) found that the more promotion offers a gifted person received as a child, the more success (e.g., publications, PhDs, patents) he or she achieved 20 years later. For instance, by using a median split, the authors reported that the group of gifted students, who received a higher degree of promotion, was about 2.3 times as likely to produce a successful publication as the group of gifted students, who formerly received a lower degree of promotion. To conclude, this study shows that promotion offers by any means benefit gifted students as long as these offers are cognitively stimulating.

Furthermore, several studies also investigated the effectiveness of specific curricula for gifted students (Gallagher & Stepien, 1996; Reis, Westberg, Kulikowich, & Purcell, 1998; Sternberg et al., 1996; VanTassel-Baska, Zuo, Avery, & Little, 2002). VanTassel-Baska and colleagues (2002), for instance, examined the effectiveness of a language arts curriculum, which was supposed to foster abstract thinking skills for gifted students. Specifically, they compared gifted students' achievement in literacy analysis and interpretation as well as in persuasive writing after having either participated in a special language arts curriculum or after having received traditional language lessons. They found that gifted learners who received the language arts curriculum highly outperformed gifted students who received traditional lessons with regard to their high-level thinking performance (i.e., literacy analysis and interpretation, persuasive writing). VanTassel-Baska et al. (2002) concluded that gifted students need differentiated curricula that particularly promote their abstract thinking skills. Gallagher and Stepien (1996), by contrast, did not find gifted students to benefit more from a problem-based history curriculum as compared to a traditional history curriculum with regard to their American history knowledge afterwards. Importantly, however, the participants of this study were particularly talented in mathematics and science so that the specialized curriculum in history might have not fitted their giftedness. In line with this idea, Sternberg and colleagues (1996) demonstrated that a curriculum that was appropriately matched to the gifted learners most benefitted their achievement. More precisely, Sternberg and colleagues assessed the students' patterns of ability, namely their analytical, creative, and practical ability, and either assigned a gifted student to a curriculum that matched his or her ability pattern or to a curriculum that did not perfectly fit to the student's ability pattern. Sternberg and colleagues found that those gifted students who received a curriculum that matched their pattern of ability outperformed those students who were mismatched. To conclude, as already proposed by ATI (Cronbach & Snow, 1977), promotion offers seem to be more beneficial when they are matched to the gifted learners' particular prerequisites. For instance, as indicated above (1.1.1), high cognitive potential is the most generally accepted component of giftedness (e.g., Sternberg et al., 2011) and is thus likely to also represent the most common characteristic among students having been identified as gifted. Accordingly, it would be reasonable to provide learning offers that capitalize on the students' high cognitive potential by stimulating more complex learning processes in order to further develop the students' cognitive potential. However, whether such a precise match between the gifted learners' prerequisites and a specific learning offer is considered when identifying gifted students for promotion offers in the practical context is doubtful. In the following, the present dissertation will thus dwell on the practical approach to gifted identification, concluding with implications for respective promotion offers.

1.1.4 Linking theory to practice: Gifted identification in the practical context

The theoretical claim for a multidimensional gifted identification procedure as well as for a fine-grained matching of the identification procedures to the corresponding promotion offers does (unfortunately) not automatically guide practical acting (e.g., Friedman-Nimz, 2009; Steinheider, 2014); or as Renzulli briefly states "translating theory into practice is always a challenging task" (2005, p. 270). The fact is that one rarely finds gifted identification procedures that actually satisfy these demands in the practical context (Friedman-Nimz, 2009). This is not surprising as multidimensional assessments are financially and timely more costly for practitioners than single assessments so that the latter seems to be more appealing within the practical context. Moreover, matching identification procedures to the specific promotion offers requires practitioners to invest more mental effort than just applying the same procedure on every occasion. Thus, it is reasonable that practitioners are not willing to invest such a high degree of mental, financial, and time resources to fulfill theoretical propositions, but rather select identification procedures on the basis of availability and convenience. Accordingly, gifted identification procedures that are based on a single assessment can be found most often in the practical context (Friedman-Nimz, 2009). In this vein, several studies have already examined which procedures are applied most often among practitioners (Adderholdt-Elliot, Algozzine, Algozzine, & Haney, 1991; Feldhusen & Sayler, 1990; Neber, 2004; Schroth et al., 2008). For instance, Adderholdt-Elliot and colleagues (1991) investigated identification practices among 38 state directors of gifted education programs in the United States. Adderholdt-Elliot and colleagues reported that teachers' nominations were used in more than 90% of all cases, individual ability tests in 70%, and individual achievement tests in 66% within the responding states. Surprisingly, the authors also pointed out that parents' nominations were used in about 80% of the states. Moreover, Feldhusen and Sayler (1990) conducted a survey evaluation of special classes for gifted in the State of Indiana, United States. They reported that teacher nominations were the most frequently used method to select children for special classes with 97%. Again parent nominations unexpectedly revealed to be frequently used by 72% of the special classes. Individual ability tests and achievement tests, by contrast, were only used by 52% or 47% of the special classes. The most rarely used method, however, was self- or peer nomination with 22%. In a more recent study, Schroth et al. (2008) examined the preferred gifted identification method of school educators in a random sample of public school districts in the United States. The authors reported that more than 80% of the educators considered teacher nominations (86.9%) and standardized tests (84.7%) to be most effective when identifying gifted children. Parent and peer nominations proved to be less preferred methods and were only considered by 39.7% and 31.2% of the educators to be effective. Lastly, a German study by Neber (2004) that focused on the gifted selections for a German enrichment program, namely the German Pupils Academy, revealed that a great emphasis was put on teachers' judgments. Specifically, 90% of the potential students for the enrichment program were nominated by teachers.

To conclude, in the practical context, teacher nominations are deemed very important and are most frequently used (Hodge & Cutmore, 1986; Rost & Buch, 2010). However, when selecting teacher-nominated gifted children for promotion offers, it is not guaranteed that these children might actually benefit from the promotion. More precisely, as teachers' selections do typically not include a precise assessment of the students' particular learning prerequisites, it is doubtful whether the students' prerequisites match with the specific promotion offers. Proceeding from the assumption that the practical approach to gifted identification is not about to change in the near future, it would be reasonable to adapt promotion offers to these children. Hence, according to ATI (Cronbach & Snow, 1977) and for the sake of effectiveness, it would make sense to determine the specific learning prerequisites of teacher-nominated gifted children and to consequently adjust respective promotion offers (cf. Heller, 1999). In line with this reasoning, one goal of the present dissertation is to examine the specific learning prerequisites of teacher-nominated gifted children. Therefore, in the following, the specific characteristics of these children will be discussed, thereby concluding with a so far relatively unattended construct, namely working memory, which will be focused in the second part of the theoretical introduction (1.2).

Characteristics of teacher-nominated gifted children

Given that teachers see, interact, and assess students constantly, they are assumed to (theoretically) take a broad range of students' characteristics into account when deciding whether a student is gifted or not (Siegle, 2001). In line with this reasoning, several studies have shown that various characteristics, namely demographic characteristics as well as cognitive and non-cognitive characteristics of the students, influence teachers' nominations (e.g., Endepohls-Ulpe & Ruf, 2005; Hernández-Torrano, Prieto, Ferrándiz, Bermejo, & Sáinz, 2013; Kim, Shim, & Hull, 2009; Siegle, Moore, Mann, & Wilson, 2010; Siegle, & Powell, 2004). With regard to demographic variables, for instance, studies revealed that gender significantly influences teachers' giftedness nominations (Bianco, Harris, Garrison-Wade, & Leech, 2011; Endepohls-Ulpe & Ruf, 2005; Hernández-Torrano et al., 2013). More precisely, Bianco and colleagues (2011) found that female students were much less likely to be nominated as gifted than male students (Cohen's d = .81). Moreover, whereas male students are generally considered to be more gifted in mathematical and science areas, female students are ascribed to be more talented in arts and language (Gagné, 1993; Lee, 2002). Furthermore, McBee (2006) demonstrated that children from minority groups and with low socioeconomic status (SES) were less likely to be nominated for gifted promotion programs. Specifically, whereas in a group of students with high SES 12.9% were nominated as gifted, in a group of students with low SES only 2.9% were nominated as gifted.

Research on non-cognitive characteristics for gifted nomination is still inconsistent. On the one hand, some studies have shown that teachers ascribe positive characteristics to gifted students such as high achievement motivation, high self-confidence, or high emotional maturity, which are consequently assumed to positively impact teachers' nominations (Chan, 2000; Endepohls-Ulpe, 2004; Moon & Brighton, 2008; Persson, 1998). On the other hand, however, some studies also found teachers to ascribe negative characteristics to gifted students such as having poor social skills or being rebellious (Copenhaver & McIntyre, 1992; Moon & Brighton, 2008). Moon and Brighton (2008), for instance, reported that teachers generally associate more positive characteristics to the gifted but also consider this target group critically. Specifically, about 90% of the teachers ascribed positive characteristics to gifted students such as being hard workers or making people laugh with clever jokes. Concurrently, however, more than 80% of the teachers also perceived gifted students to have poor social skills and to misbehave in school.

Notwithstanding the above, most research in this context has been devoted to cognitive characteristics (e.g., Endepohls-Ulpe & Ruf, 2005; Hany, 1995; Hernández-Torrano et al., 2013; Kim et al., 2009; Moon & Brighton, 2008; Rost & Hanses, 1997). This is in line with the theoretical reasoning above (see 1.1.1), namely that cognitive characteristics should be deemed most important in the context of giftedness as they represent the lowest common denominator across all giftedness conceptions. Accordingly, teachers also indicate that they consider cognitive characteristics to be most important in the context of giftedness (Endepohls-Ulpe & Ruf, 2005; Hernández-Torrano et al., 2013). Endepohls-Ulpe and Ruf (2005), for instance, invited teachers to list indicators for giftedness that they consider important. The highest proportion of mentioned features was associated with cognition (41.4%), followed by motivational features (33.1%), and a small amount of features associated with social behavior and personality traits (15.5% and 9.4%). Endepohls-Ulpe and Ruf (2005) concluded in line with other researchers that teachers tend to define giftedness mainly in terms of high cognitive potential that is associated with learning and achievement (e.g., Kim et al., 2009; Moon & Brighton, 2008). Certainly, one of the most important cognitive characteristics influencing achievement is intelligence (e.g., Dodonova & Dodonov, 2012; Spinath, Freudenthaler, & Neubauer, 2010). However, it has been found that not all students nominated as gifted by teachers exhibit outstanding high-intelligence (see also 1.1.2; e.g., Gear, 1978; Neber, 2004; Schulthess, Neuenschwander, & Herzog, 2008). Thus, further cognitive variables that are associated with achievement might also characterize these children. In this sense, further cognitive characteristics such as divergent thinking, good comprehension, good memory, reading abilities, or creativity have already been empirically investigated in this context and have also been found to play a role for teachers' giftedness nominations (Endepohls-Ulpe & Ruf, 2005; Hany, 1995; Hernández-Torrano et al., 2013; Kim et al., 2009; Moon & Brighton, 2008; Rost & Hanses, 1997). For instance, some studies reported that particularly advanced reading abilities made teachers consider a child as gifted (Hodge & Kemp, 2006; Siegle et al., 2010). Siegle et al. (2010) even demonstrated reading abilities to influence teachers' giftedness decisions more strongly than mathematical skills (Cohen's d = .29).

However, there is one important cognitive construct that has not been regarded as a characteristic for teacher-nominated gifted children yet, although it might well be as important as intelligence in the educational context, namely working memory (e.g., Baddeley, 2002; Cowan, 1999; Logie, 2011). Working memory has not only been shown to considerably affect learning achievement (e.g., Seigneuric & Ehrlich, 2005; Swanson, 2011; Swanson, Orosco, Lussier, Gerber, & Guzman-Orth, 2011), but it has also been reported to be a better predictor of later school achievement than intelligence, especially for younger children (Alloway & Alloway, 2010; Hoard, 2005). Contrary to intelligence, which is associated with higher-level cognitive functioning (e.g., logical reasoning, induction), working memory mainly captures low-level cognitive processes (e.g., storing, manipulating). Consequently, the cognitive processes associated with working memory can be assumed to supplement those associated with intelligence. Thus, both cognitive constructs are independently deemed important for learning and achievement. This is in line with Sternberg's componential theory of intellectual giftedness (1981), which emphasizes the importance of both high- and low-level cognitive processes. More specifically, on the one hand, Sternberg describes high-level processes (e.g., making analogies, detecting relations between objects), which can be ascribed to intelligence, and on the other hand, he describes low-level processes (e.g., planning, monitoring, acquiring or retaining knowledge), which can be ascribed to working memory. According to Sternberg, for a superior cognitive functioning an effective interaction of both high- and low-level cognitive processes is necessary.

To conclude, working memory is likely to play an essential role in the context of giftedness and teacher nominations. More precisely, working memory is not only considered a crucial cognitive variable in the educational context (e.g., Swanson, 2011) but can also be qualitatively distinguished from intelligence (cf. Sternberg, 1981), meaning that both variables contribute independently to cognitive functioning and, thus, to achievement (e.g., Alloway & Alloway, 2010). As teachers' giftedness nominations mainly depend on cognitive variables that influence learning and achievement, working memory is a likely candidate to represent such a cognitive variable, even besides intelligence. Importantly, this reasoning is also in line with the assumption that cognitive potential is the most commonly accepted and thus most important component for the conceptualization of giftedness. Assuming that working memory capacity constitutes a fundamental cognitive potential (besides intelligence) that attributes to high cognitive functioning, it may also represent one of the most common characteristics among gifted students in general and of teacher-nominated gifted students in particular. However, working memory has not yet played an important role in research about characteristics of teacher-nominated gifted students. Therefore, one goal of the present dissertation is to extend previous literature about characteristics of teacher-nominated gifted children by focusing on working memory. In the following second part of the introductory chapter, the construct of working memory will be explored in more detail.

1.2 Working Memory

Working memory (WM) can be described as a system for temporarily storing and manipulating information during cognitive activity (Baddeley, 2002). The capacity of this WM system, however, is limited (e.g., Tuholski, Engle, & Baylis, 2001). Importantly, WM has been shown to be of particular relevance during information processing and to be associated with a wide range of high-level cognitive abilities such as reasoning ability or problem solving (e.g., Baddeley, 1986; Kyllonen & Christal, 1990). Therefore, it is not surprising that WM is a crucial construct in cognitive psychology (e.g., Anderson, 1983; Baddeley, 1986), and recently also in cognitive neuroscience (e.g., Yarkoni & Braver, 2010).

The term WM dates back to the work of Miller, Galanter, and Pribram (1960) who analyzed the control and execution of action plans. In this vein, they introduced the concept of WM as an instance that, on the one hand, controls cognition and actions and, on the other hand, simultaneously stores information. Further, Atkinson and Shiffrin (1971) described a memory model comprising a sensory store, a short-term memory (STM), and a long-term memory. They proposed the sensory store to receive all incoming information first. Therefrom a limited amount of information is forwarded to STM. Importantly, only information that is paid attention to is passed onto STM, which is, therefore, considered as a capacity-limited memory store or as a bottleneck, respectively. Herein, information is temporarily processed and forwarded to long-term memory, which represents an unlimited memory store, from which information can also be retrieved at a later time. As Atkinson and Shiffrin assumed STM to not only temporarily store information but also to be involved in the processing of information, they ultimately referred to it as WM. In line with this, memory researchers in general conceded that the term STM was insufficient to describe the complex processing that was gradually associated with this memory system (Baddeley, 2012; Yuan, Steedle, Shavleson, Alonzo, & Oppezzo, 2006). Consequently, the term WM was widely disseminated and STM was rather considered to be a subset of WM (Engle, Tuholski, Laughlin, & Conway, 1999b; Unsworth & Engle, 2007). Since then, several researchers have proposed various models to conceptualize WM (e.g., Baddeley & Hitch, 1974; Engle, Kane, & Tuholski, 1999a; Logie, 2011; Oberauer, Süß, Schulze, Wilhelm, & Wittmann, 2000). A clear common agreement about what exactly constitutes WM, however, has not been reached yet (Kyllonen, 2002). While most researchers agree that WM consists of multiple interacting subsystems, there are important differences on how the structure of these subsystems is further conceptualized (e.g., Engle et al., 1999a; Logie, 2011; Oberauer et al., 2000). In order to give an impression of such differing WM conceptualizations, the four most important WM models will be shortly described in the following section. Note, however, that this review is not exhaustive.

1.2.1 Models of working memory

In this section, four popular WM models originating from different research traditions will be sketched. First, the multiple-component model of working memory by Baddeley and colleagues (e.g., Baddeley, 2012; Baddeley & Hitch, 1974; Baddeley & Logie, 1999; Logie, 2011), which originates from human cognitive psychology research and is arguably one of the most influential WM models, will be described. Subsequently, two models with an attentional-based account of WM functions will be introduced, namely the “controlled attention” framework by Engle and colleagues (1999a) and the embedded process model by Cowan (1999; 2005). Whereas the “controlled attention” framework by Engle et al. (1999a) conceptualizes WM as consisting of two components, namely STM and controlled attention, the embedded process model by Cowan (1999; 2005) considers WM to be an attentional focus that temporarily activates certain areas of long-term memory. Finally, this review will conclude with a more current but (simultaneously) also more complex design of WM by Oberauer (2009), who emphasizes a functional approach to constitute the WM system as part of a larger cognitive architecture.

The multiple-component model of working memory

The multiple-component model of working memory by Baddeley and colleagues (Baddeley, 2012; Baddeley & Logie, 1999; Logie, 2011) is based on the seminal tripartite structure proposed by Baddeley and Hitch (1974). According to Baddeley and Hitch (1974), WM consists of three components: the central executive, the phonological loop, and the visuospatial sketchpad. Whereas the central executive is defined as an attentional control system, the two other components are considered as slave systems responsible for keeping the to-be-processed information active in memory. Specifically, spatial or visual information is stored in the visuospatial sketchpad, whereas verbal information is stored in the phonological loop. The central executive, by contrast, is responsible for actively manipulating the temporarily stored information. Within the original model by Baddeley and Hitch (1974) the central executive was hardly specified but was rather considered as a conglomeration of all complex strategies that are needed when a learner wants to accomplish a task successfully (e.g., selection, planning, and retrieval checking). In later versions of the multiple-component model, however, the conceptualization of the central executive was more and more specified. In this vein, for instance, Baddeley (1996) ascribed four functions to the central executive, namely focusing attention, dividing attention between two important targets, switching between tasks, and holding and manipulating information in long-term memory.

Due to several behavioral, developmental, and neuropsychological experiments, the multiple-component model of working memory has been further developed over nearly four decades (Baddeley, 2012; Logie, 2011). Currently, it describes several domain-specific cognitive functions that all have to act together in order to meet respective task demands (Logie, 2011). One cognitive function can be regarded as a visual STM, namely the visual cache, formerly described as the visuo-spatial sketchpad. The visual cache temporarily stores visuo-figural information and is believed to be fractionated into separate visual, spatial, and kinesthetic components (Baddeley & Logie, 1999). A concomitant function is labeled “inner scribe” and is supposed to retain short sequences of movements. Verbal sequences, by contrast, are kept in a phonological store, formerly described as the phonological loop. A concomitant function, labeled “inner speech”, is responsible for mentally repeating respective verbal sequences. Both, the visual cache as well as the phonological store are associated with executive functions. Contrary to earlier specifications of the central executive (e.g., Baddeley, 1996; Baddeley and Hitch, 1974), a range of executive functions is proposed including focusing and sustaining attention, task switching, updating, inhibition, encoding, and retrieval (Baddeley, 2007). Whereas these executive functions are assumed to process incoming information, the other cognitive functions, namely the visual cache and the phonological store, are designed to temporarily store the respective information. Contrary to the original tripartite structure (Baddeley & Hitch, 1974), Baddeley (2000) added an episodic buffer to the multiple-component model, which is considered to enable the interaction between working memory components and episodic and semantic long-term memory. Specifically, the episodic buffer is assumed to hold multidimensional episodes or chunks that can be merged with perceptual information as well as with experiences and knowledge from long-term memory (Baddeley, 2010). In sum, the multiple-component model of working memory is a more sophisticated derivative of the originally proposed model by Baddeley & Hitch (1974). Due to several experiments, it can be considered as an empirically valid conception of WM in the tradition of human cognitive psychology (Logie, 2011).

The controlled attention framework

The “controlled attention” framework by Engle and colleagues (1999a) considers WM to be a system containing a STM store and a unitary control system that is labeled controlled attention. Thus, to a certain degree this model shares a similar architecture with the multiple-component model (e.g., Baddeley & Logie, 1999). Specifically, both models conceptualize storing components (i.e., slave systems vs. STM) and a unitary control system (i.e., central executive/ executive functions vs. controlled attention). Importantly, however, both models stem from different research traditions. That is to say, whereas the multiple-component model originates from human cognitive psychology, the controlled attention framework originates from differential psychology, which particularly focuses on interindividual differences in WM capacity. As a result, the detailed functioning of the components in the controlled attention framework is quite different from those conceptualized in the multiple-component model. More precisely, the controlled attention component is suggested to be responsible for maintaining currently relevant information in a highly active state even if distracting and/or interfering information occurs. Thereby, activation is achieved by activating long-term traces through controlled retrieval. STM, by contrast, is assumed to consist of traces that are active above threshold but that are not in the focus of attention any more. Engle and colleagues also describe the controlled attention component as an executive control capability. In more recent studies, they even redefined the term controlled attention to executive attention (e.g., Kane, Poole, Tuholski, & Engle, 2006). According to Engle and colleagues, WM capacity reflects the extent to which a person can resist interference and can inhibit distractions while actively maintaining information. Whereas some researchers proposed attentional inhibitory capabilities to primarily constitute WM capacity (e.g., Hasher & Zacks, 1988), Engle and colleagues are convinced that the controlled attention capability drives inhibition and therefore constitutes WM capacity (e.g., Kane, Bleckley, Conway, & Engle, 2001). Importantly, Engle and colleagues claim controlled attention to be a domain-free capability, which is independent of the material to be processed. Thus, an individual's controlled attention is considered to be independent of specific skills in a certain domain area (e.g., mathematics, reading, etc.). In sum, the controlled attention framework focuses on interindividual differences in a person's controlled attention, which is considered to be the crucial component that primarily makes up WM. Therefore, the empirically found high associations of WM with complex cognitive abilities (e.g., Kyllonen & Christal, 1990) are assumed to be caused by an individual's degree of controlled attention.

The embedded process model of working memory

Similar to the attentional control framework (Engle et al., 1999a), the embedded process model by Cowan (1999; 2001; 2005) also emphasizes an attentional-based account of WM functions. Specifically, the model by Cowan highlights the role of an attentional focus that temporarily activates certain areas of long-term memory. Contrary to the two former models described (i.e., the multiple-component model, the controlled attention framework), however, the embedded process model does not conceptualize different WM components (i.e., STM, controlled attention, central executive, slave systems) but describes WM as well as STM to be embedded in long-term memory. More precisely, the information, which WM is going to process, is not stored in a dedicated component such as, for instance, the slave systems (e.g., Baddeley & Hitch, 1974). Instead, WM receives information from a currently activated subset of long-term memory. This activated subset is assumed to be in the present focus of attention. Importantly, only information that is currently in the focus of attention is available in WM. The activation of a specific subset in long-term memory, however, easily fades unless verbal rehearsal processes are undertaken or the attentional focus maintains on the specific subset. Thus, retrieving information repeatedly into the focus of attention by rehearsal processes increases their level of activation in long-term memory so that this information will be more available than information that is less rehearsed. Some subsets may be in a higher state of activation but yet outside of the attentional focus. Although information associated with these subsets is outside of conscious awareness, it can still influence ongoing processes. Moreover, the attentional focus is assumed to have limited capacity in that only four chunks can be simultaneously held in memory. Note, however, that each chunk is supposed to contain more than a single item (Cowan, 2005). In sum, Cowan's embedded process model considers WM as an activated portion of long-term memory. Contrary to the multiple-component model (Baddeley & Logie, 1999) and the controlled attention framework (Engle et al., 1999a), it can thus be described as a unitary WM structure.

Oberauer's functional design of a working memory model

Contrary to the three WM models described above (i.e., multiple-component model, controlled attention framework, embedded process model), Oberauer's functional design of a working memory model (2009) is a relatively novel but also more complex conceptualization of WM. Importantly, Oberauer's model is not empirically derived but rather constitutes the WM system as part of a larger cognitive architecture. That is to say, Oberauer (2009) describes functions that a WM system has to fulfill in order to meet the requirements of such a large cognitive architecture. Specifically, Oberauer (2009) assumes WM to represent a system that serves complex cognitions such as language comprehension, reasoning, or creative problem solving. In order to adequately serve these cognitions, Oberauer postulates six demands that a WM system has to meet. First, such a system must be able to maintain new structural representations (e.g., new sequences of actions in a plan or new constellations of pieces on a chessboard). Second, it must have a mechanism for manipulating such representations, and third, to flexibly reconfigure them. Fourth, it is important that representations in WM are partially decoupled from long-term memory. Fifth, WM must be able to retrieve contents from long-term memory. Finally, the WM system must be able to build new structural representations that can be transferred into long-term memory. On the basis of these functions, Oberauer sketches an architecture of WM that distinguishes between declarative and procedural WM. The declarative part is considered to make representations available for processing and is thus labeled the memory part, comparable to STM (Engle et al., 1999a) or the storage functions within the multiple-component model (e.g., Baddeley & Logie, 1999). More specifically, the declarative part of WM can be decomposed into three components: the activated part of long-term memory, the region of direct access, and the focus of attention. These three components are comparable to Cowan's (1999) conceptualization of WM in that WM is an activated part of long-term memory, which is temporarily maintained accessible by focusing attention on it. Importantly, all three components are responsible for the construction and manipulation of representations with each component further limiting the set of representations than the previous component. The procedural part, by contrast, is mainly involved in the processing itself and is therefore labeled the working part, comparable to the central executive (Baddeley & Logie, 1999) or to the attentional control (Engle et al., 1999a). The procedural part of WM consists of the same components as the declarative part (i.e. the activated part of long-term memory, the region of direct access, and the focus of attention). However, contrary to the declarative part, which is concerned with the representation and selection of the contents of the cognitive activity, the procedural part is concerned with the cognitive operations themselves. Similar to the declarative components, each component narrows down the set of selected representations from the former. Contrary to other conceptions that consider one part of WM to be more important than others (e.g., the central executive component in Baddeley's WM model (1996); or the controlled attention component in the Engle and colleagues' framework (1999a)), Oberauer ascribes equal importance to both the declarative and procedural part of WM. However, empirical evidence for this model is scarce so far. This is not surprising as the complexity of the model makes a valid evaluation difficult.

As can be seen from the depicted models above, researchers differ widely in their conceptualization of WM. For instance, whereas Baddeley and Logie, (1999; multiple-component model), Engle et al. (1999a; controlled attention framework), and Oberauer (2009; functional design of WM) conceptualize WM as consisting of at least two different components, Cowan (1999; embedded process model) considers WM to be a unitary structure. Moreover, whereas Baddeley and Logie (1999) specify two different systems (i.e., visual cache and phonological store) that store either visuo-spatial or verbal information, the other researchers assume WM not to be domain-specific (see also Table 2 for a comparative description of the models). However, these different conceptualizations of WM are not surprising as the different models stem from different research traditions and were thus designed for different reasons. Specifically, the multiple-component model (Baddeley & Logie, 1999) originates from human cognitive psychology research and focuses on how different cognitive processes interact within a detailed WM structure. The controlled attention framework (Engle et al., 1999a), by contrast, originates from differential psychology and rather focuses on how interindividual differences in WM capacity can be best conceptualized by using an attentional-based approach. Although Cowan (1999; 2005) also focuses on an attentional-based account of WM functions, his embedded-process model particularly describes the functionality of a WM system without differentiating between different components. Finally, Oberauer's functional design of a working memory model (2009) considers the WM system to be part of a larger cognitive architecture. Therefore, this model primarily focuses on the specific functions that have to be fulfilled by the WM system in order to meet the requirements of such a complex and large cognitive architecture. To conclude, all models describe WM from different perspectives, thereby emphasizing different aspects or phenomena (e.g., component structure, interindividual differences, functionality). Thus, which WM model might be most suitable for a given situation, strongly depends on the specific research goal so that from a theoretical point of view each WM model should receive recognition.

Table 2

Description of the Four WM Models on the Basis of (1) their Unitary or Multiple-Component Structure, (2) their Functionality, (3) their Relation to Long-Term Memory, and (4) their Domain-Specificity

Working memory models	*(1) Unitary vs. multiple-component structure*	*(2) Functionality of the WM system*	*(3) Relation to long-term memory*	*(4) Domain-specificity*
The multiple-component model (Baddeley & Logie, 1999)	Multiple-component structure: visual cache (+ inner scribe), phonological store (+ inner speech), executive functions, episodic buffer, episodic and semantic long-term memory	Visual cache and phonological store store visuospatial and verbal information; executive functions process information: focusing and sustaining attention, task switching, updating, etc.; episodic buffer enables interaction with long-term memory; long-term memory provides knowledge and thus enables top-down processes	Episodic buffer enables interaction with long-term memory which provides semantic experiences and knowledge	Storing is assumed to be domain-specific and takes place in two subsystems: visual cache for visuospatial information and the phonological store for verbal information
The controlled attention framework (Engle et al., 1999a)	Two-component structure: STM and controlled attention component	STM stores information; controlled attention: maintains currently relevant information in a highly active state even if distracting and/or interfering information occurs (controlled attention part is deemed most important); focus on interindividual differences in WM capacity	Activation of information is achieved by activating traces in long-term memory	Controlled attention is a domain-free capability
The embedded process model (Cowan, 1999)	Unitary structure (that emphasizes the focus of attention)	WM is an activated portion of long-term memory; attentional focus temporarily activates certain long-term memory areas	WM receives information from activated subsets of long-term memory	Not specified; focus of attention is rather perceived as a domain-free capability
The functional design of a working memory model (Oberauer, 2009)	Multiple-component structure within a large cognitive architecture: declarative part and procedural part of WM; each part is again decomposed into three components (activated part of long-term memory, region of direct access, focus of attention)	WM has to meet several demands (maintaining, manipulating, and flexibly reconfiguring structural representations, decoupling, retrieving, and transferring representations from/ to long-term memory); declarative part makes representations available for processing, procedural part processes and cognitively operates (both parts are deemed equally important)	WM is an activated part of long-term memory, which is temporarily maintained accessible by focusing attention on it	Not specified; processing is rather perceived to be content-independent

1.2.2 An operational definition of working memory

Whereas the conceptualization of WM has evoked some controversies, there is rather common agreement about its operationalization, particularly if the research focus is on individual differences in WM capacity. That is to say, WM resources are generally assessed with tasks that demand the active storing of information and the simultaneous executive processing of information (e.g., Yuan et al., 2006). More specifically, whereas storing refers to the memorization of recently presented information for a very short time, executive processing refers to the manipulation or transformation of information (Oberauer, 2005). Corresponding tasks that assess WM capacity are labeled complex span tasks. These measures involve the simultaneous storage and executive processing of information and are normally used in cognitive psychology research (e.g., Baddeley, 2002). A typical example is the reading span task (Daneman & Carpenter, 1980). Herein, a person has to read a sequence of sentences and has to memorize the last word of each sentence (storage). Simultaneously, he or she has to verify each sentence by stating "true" or "false" (executive control). After a series of several sentences, the person has to recall the final word of each sentence in the correct order. Another standard WM measure is the n-back task. Note, however, that the n-back task is rather used in neuroscience than in cognitive psychology research (e.g., Jaeggi, Buschkuehl, Perrig, & Meier, 2010). The n-back task demands to decide for each presented stimulus whether it matches the one presented n items before (cf. Jaeggi et al., 2010). Thus, it requires to remember the last n items presented (storage) and to continuously update the set of items (executive control). On the basis of these two WM functions (i.e., storage and executive processing), a clear distinction between WM tasks and STM tasks can be derived. Contrary to WM tasks, STM tasks require the mere storing of information and are referred to as simple span tasks (Engle et al., 1999b; Unsworth & Engle, 2007). As the operationalization of WM and STM described above is widely accepted among researchers, the present dissertation rather refers to an operational definition of WM instead of committing itself to one distinct WM model. A conceptualization of this operational definition is depicted in Figure 1.

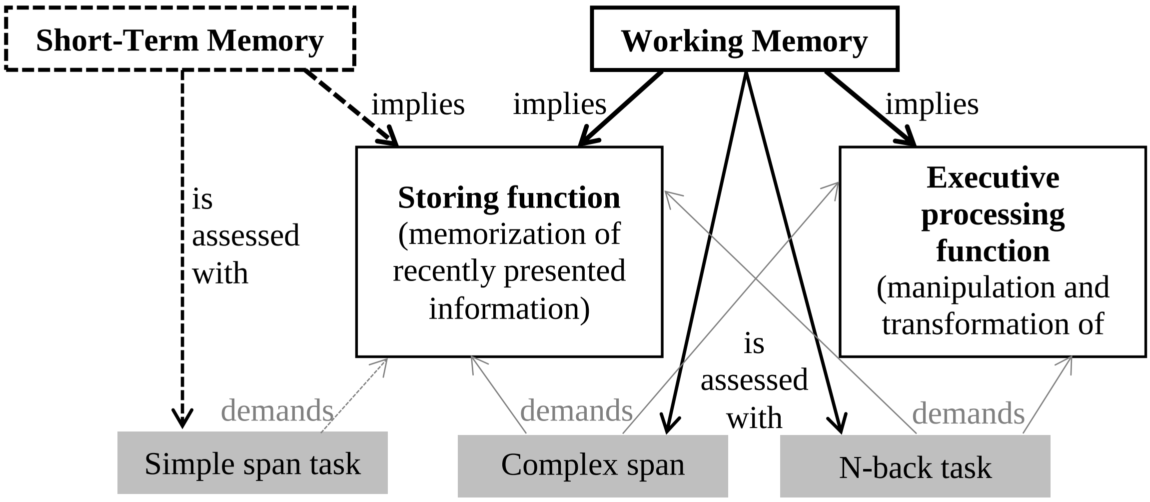

Figure 1. Conceptualization of an operational definition of WM (and also STM) pointing up the functions of WM (i.e., storing and executive processing) as well as the tasks that demand corresponding functions (i.e., complex span task, n-back task). STM, by contrast, is only associated with the storing function and is correspondingly assessed with simple span tasks.

1.2.3 Working memory and other cognitive constructs

Various studies have related the construct of WM to other cognitive variables in order to classify WM within a nomological network that clarifies its specific meaning and potential (e.g., Ackerman, Beier, & Boyle, 2002; de Jong & Das-Smaal, 1995; Engle et al., 1999b; Fry & Hale, 1996; Kyllonen & Christal, 1990). Unsurprisingly, most research focused on the relationship between WM and the prestigious construct of intelligence (e.g., Kyllonen & Christal, 1990). Nevertheless, the relation of WM with further cognitive variables such as processing speed, STM, or executive functions has also been object of investigation in this context (e.g., Ackerman et al., 2002; Miyake, 2001). In the following, these relations will be described in more detail.

Working memory and intelligence

Several studies have indicated strong correlations between WM and intelligence, particularly with fluid intelligence, both for adults (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Kyllonen & Christal, 1990) and for children (de Jong & Das-Smaal, 1995; Fry & Hale, 2000; Vock, 2005). This might be due to the fact that WM and intelligence represent partially overlapping constructs. Specifically, WM is assumed to be an underlying cognitive system that enables complex cognitions associated with intelligence such as reasoning (e.g., Kyllonen, 1996). That is to say, with regard to reasoning tasks, for instance, interim results have to be stored in WM while the task is continued. Furthermore, WM is important for the memorization of rules or solution principles across several items of an intelligence test (Verguts & de Boeck, 2002). Thus, a limited WM capacity might bias preceding solution steps and, thus, might negatively affect reasoning and intelligence test scores (e.g., Carpenter, Just, & Shell, 1990; Shah & Miyake, 1996).

Although there is no doubt that WM and intelligence are highly correlated, there are inconsistencies about the extent to which they are correlated and consequently, which meaning can be ascribed to WM. Some researchers have argued that the association between WM and intelligence is so strong that both represent more or less the same construct (Engle, 2002; Jensen, 1998; Kyllonen & Christal, 1990; Kyllonen, 1996; Kyllonen, 2002). For instance, in the often cited study by Kyllonen and Christal (1990), the correlation between WM and intelligence was found to be close to r = .90, so that both constructs were assumed to be nearly equal. In a follow-up study (Kyllonen, 1996), the correlation between WM and intelligence even amounted to r = .96. However, it has to be noted that a part of these tasks to measure WM or intelligence were quite similar so that the validity of these findings might be limited. Notwithstanding, most studies that investigated the relation between WM and intelligence across different samples, age groups, as well as with different types of WM and intelligence measures found correlations between r = .40 and r = .70 (Colom, Flores-Mendoza, & Rebollo, 2003; Conway et al., 2002; de Jong & Das-Smaal, 1995; Engle et al., 1999b; Oberauer et al., 2000). Accordingly, in a meta-analysis by Ackerman, Beier, and Boyle (2005), a medium correlation between WM and fluid intelligence was found (r = .48) so that it is most likely that both constructs are closely related but still not the same. As mentioned before, WM represents a low-level cognitive system that conducts rather simple cognitive operations, namely storing and executive processing. By contrast, (fluid) intelligence can be described as higher-level cognitive functioning including complex cognitions such as logical reasoning, problem solving, making analogies, or inductive thinking (Cattell, 1961; Süß, Oberauer, Wittmann, Wilhelm, & Schulze, 2002). Specifically, fluid intelligence is characterized by the ability to understand complex relationships and to solve novel problems (Martinez, 2000). Similar to the various WM models, the structure of intelligence is differently conceptualized by several intelligence models such as, for instance, the theory of *g* by Spearman (1927), the model of primary mental abilities by Thurstone (1938), or the structure of intellect by Guilford (1988). However, as intelligence does herein not represent the focal construct, it would go beyond the scope of the present dissertation to further dwell on the different intelligence models. To conclude, WM and fluid intelligence are considerably correlated but still reflect different cognitive processes, namely low-level cognitive processes (WM), on the one hand, and high-level cognitive processes (intelligence), on the other hand.

Working memory and processing speed

Comparable to WM, processing speed represents a crucial construct for information processing (Kyllonen, 1996). According to Jäger and colleagues (2005), processing speed is conceptualized as the work pace, the apprehension, and the ability to concentrate while solving simple tasks. Importantly, processing speed is assumed to explain individual differences in various cognitive tasks (Kyllonen, 1996). For example, several researchers suggest processing speed to be a mediating factor between WM and fluid intelligence (e.g., Kail & Salthouse, 1994; Jensen, 1998). Specifically, Baddeley (1986) assumed that a faster processing speed would also lead to faster rehearsal processes in WM so that more information could be kept active for a certain time. Accordingly, a faster processing speed might increase the probability to finish an intelligence task before the necessary information, such as interim results or specific rules, have decayed from WM (Jensen, 1998).

Empirical studies have found positive correlations between WM and processing speed, however, less robust as compared with correlations between WM and intelligence. For instance, Oberauer and colleagues (2000) only found correlations between $r = .19$ and $r = .31$. In a study by Kyllonen and Christal (1990) the correlation amounted at least up to $r = .48$ and in a study by Ackerman et al. (2002) even up to $r = .55$. For children at the age of 9 years a correlation of $r = .60$ between WM and processing speed was found (de Jong & Das-Smaal, 1995). To conclude, WM and processing speed, which both play a crucial role in information processing, seem to overlap meaningfully. Still, they are less strongly associated than WM and intelligence.

Working memory and short-term memory

WM originally evolved from the former model of STM (Engle et al., 1999b). As already introduced above, STM incorporates a storage function but is not assumed to be involved in executive processing activities (Engle et al., 1999b; Unsworth & Engle, 2007). Thus, although WM and STM have the storing component in common, they can clearly be distinguished. A study by Engle and colleagues (1999b) provided empirical evidence for the differentiation between STM and WM. Specifically, a latent variable approach revealed a two-factor model (i.e., a separation of WM and STM) to have a significantly better fit than a one-factor model (i.e., assuming WM and STM to be the same). Although WM and STM represent distinct constructs, they are highly correlated with r = .68 (Engle et al., 1999b). Regarding their relation with intelligence, however, they largely differ. Whereas WM shows strong associations with intelligence, STM is only moderately associated with the latter and even no longer significantly predicts intelligence when WM is controlled for (Conway et al., 2002; Engle et al., 1999b; Unsworth & Engle, 2007). Accordingly, Cowan (1995) considered STM to be only a subsystem of WM. To conclude, although WM and STM are apparently related to each other, they are differentially important with regard to their predictive power for higher order cognitions.

Working memory and executive functions

The concept of executive functions (EFs) has its roots in neuropsychological theories of behavioral control (e.g., Stuss & Knight, 2002). Comparable to WM, which represents an attentional control system for cognitive psychologists (e.g., Baddeley, 1986), EFs represent an executive control mechanism for neuropsychologists (Fuster, 1997). Although there are remarkable differences concerning the conceptualization of both constructs, they theoretically have a common ground. EFs are defined as processes that are geared to control goal-directed behavior or complex cognitions (Banich, 2009). For instance, EFs comprise the inhibition of dominant responses, the shifting between tasks, the monitoring and regulation of performance, the updating of task demands, goal maintenance, or planning (see McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010). In the field of EFs, it has longtime been discussed whether EFs can be conceptualized as a unitary construct or as several distinct functions (e.g., Duncan, Johnson, Swales, & Freer, 1997; Miyake et al., 2000; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). In this vein, for example, Miyake and colleagues (2000) demonstrated that three often postulated EFs, namely shifting, updating, and inhibition, can be considered as clearly separate functions that only moderately correlate. Currently, most researchers conceptualize EFs as distinct functions, however, consisting of a common underlying executive component. Therefore, in order to appropriately assess EFs, multiple tests, which capture diverse EFs, are needed (e.g., Miyake et al., 2000). One typical EFs task is the Wisconsin Card Sorting Test, in which a participant is required to sort cards based on an occasionally changing dimension, namely color, shape, or number. The Wisconsin Card Sorting Test implies EFs such as, for instance, the switching between changing task demands or the inhibition of previous sorting criteria.

There are various and partially inconsistent studies relating WM to EFs. In a study by McCabe and colleagues (2010), for instance, WM and EFs have been shown to highly correlate (r = .97). McCabe and colleagues (2010), thus, assumed WM and EFs to share a large common underlying cognitive ability that they referred to as executive attention. Moreover, they suggested EFs to be implicitly included in the concept of WM. To support their proposition, they referred to the central executive component of the multiple-component model (Baddeley & Logie, 1999). Specifically, they supposed the central executive component to incorporate several EFs such as focusing and sustaining attention, task switching, updating, inhibition, encoding, and retrieval (Baddeley, 2007), and thus to implicitly incorporate the concept of EFs. Other studies, by contrast, have found WM to be only associated with one EF, namely with the updating process, but not with other functions such as shifting or inhibition (Miyake et al., 2000; Lehto, 1996; Oberauer, Süß, Wilhelm, & Wittman, 2003; St.-Clair-Thompson, 2011; St.-Clair-Thompson & Gathercole, 2006). Thus, these researchers consider WM rather as a subcomponent of EFs in that WM is only involved in the updating process.

To conclude, there seems to be no consensus as to whether WM and EFs are independent constructs that only share a common underlying factor, whether EFs represent part of the central executive component, or whether WM represents part of a specific EF component, namely the updating component. Note, however, that there are large variations among the different studies concerning their choice of WM as well as EFs tasks, which might explain the inconsistent findings. Notwithstanding the above, WM and EFs are considered as distinct constructs as they were created for different reasons and are also assessed with different methods (cf. McCabe et al., 2010). More precisely, whereas EFs measures were originally intended to assess functioning associated with frontal lobes, complex WM span tasks were developed to assess individual differences in the ability to simultaneously store and manipulate information.

1.2.4 Educational relevance of working memory

Beyond its relation with other cognitive constructs, the cognitive construct of WM has also been shown to play a crucial role in the educational context. In general, it has been demonstrated that cognitive variables, as compared to motivational or personality characteristics, best predict school achievement (e.g., Fraser, Walberg, Welch, & Hattie, 1978). In this vein, the association between intelligence and school achievement represents arguably one of the best-established associations (Bartels, Rietveld, Van Vaal, & Boomsma, 2002; Brody, 1992; Fraser et al., 1987). In a meta-analysis by Fraser and colleagues (1987), for example, the average correlation between intelligence and school achievement was found to range between r = .34 and r = .50. Although intelligence seems to be at the forefront of cognitive variables that influence school achievement, the impact of WM should not be underestimated. In fact, WM has been found to be as predictive as intelligence of a variety of performances linked to educational achievement (e.g., Alloway & Alloway, 2010; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Toll, Van der Ven, Kroesbergen, & Van Luit, 2011). With regard to school achievement in general, studies revealed medium to strong correlations with WM (Alloway & Alloway, 2010; Gathercole, Pickering, Knight, & Stegmann, 2004; de Jong & Das-Smaal, 1995, Lehto, 1995; Lu, Weber, Spinath, & Shi, 2011). For instance, de Jong and Das-Smaal (1995) found in a latent variable approach that WM and school achievement were highly correlated with $r = .72$. Importantly, this correlation did not significantly differ from the one that the authors found for school achievement and intelligence. In other studies, WM was even reported to better predict later school achievement than intelligence, especially for younger children (Alloway & Alloway, 2010; Hoard, 2005). STM, by contrast, was generally found to be less strongly related to school achievement (e.g., Daneman & Merikle, 1996; Gathercole et al., 2004).

Importantly, WM has not only been shown to affect school achievement in general (e.g., Alloway & Alloway, 2010), but also to be associated with specific academic abilities such as mathematical problem solving (Swanson, 2011), reading comprehension (Seigneuric & Ehrlich, 2005), language learning (Leonard et al., 2007; Swanson et al., 2011), and science learning (e.g., Danili & Reid, 2004; Tsaparlis, 2005). In this vein, for instance, Tsaparlis (2005) investigated the impact of WM capacity on the performance in a chemistry problem-solving test and found both variables to be moderately correlated. Furthermore, Swanson and colleagues (2011) examined the contribution of WM to children's second language reading and language acquisition beyond phonological processing skills, which are assumed to be important cognitive determinants in the respective context. Results revealed that WM significantly predicted language reading and acquisition even after controlling for phonological processing skills. To conclude, several studies have demonstrated that WM represents an influential construct for learning and achievement that should be regarded as being at least equally important as intelligence in the educational context.

Considering the high correlations of WM with school achievement and also with complex cognitions (e.g., intelligence), it is likely to associate the construct of WM with giftedness, which is also most commonly associated with high cognitive potential and achievement (Sternberg & Davidson, 2005). Therefore, in the final section of this part, WM will be embedded within the field of giftedness pointing to its importance in the context of teacher-nominated gifted children. Referring back to ATI (Cronbach & Snow, 1977), this section closes by introducing learning offers that seem to be appropriate for students who are characterized by high WM capacity.

1.2.5 Working memory, giftedness, and appropriate learning offers

The construct of WM has not received great attention in the field of giftedness yet. There have only been a few studies investigating the role of WM in gifted children. Most often, these children had been identified by a cognitive achievement test or an intelligence test (Hoard, 2005; Hoard, Geary, Byrd-Craven, & Nugent, 2008; Swanson, 2006; Vock, 2005). In sum, these studies revealed that gifted children exhibited a higher WM capacity than non-gifted children. Moreover, a few of these studies additionally considered the STM of these children and yielded inconsistent results (Hoard et al., 2008; Swanson, 2006). That is to say, whereas Hoard et al. (2008) supported the notion that gifted children have a higher WM as well as a higher STM capacity than non-gifted children, Swanson (2006) only found WM capacity to be superior in gifted children. Notwithstanding these inconsistencies for STM, high WM capacity seems to be a crucial characteristic in intellectually gifted children. According to Vock and Holling (2008), WM measures can therefore be assumed to be a valuable extension to intelligence tests when identifying intellectually gifted children.

As already outlined in the first part of the introduction (1.1.4), the present dissertation focuses on teacher-nominated gifted children, who are also likely to be characterized by high WM capacity. For teacher-nominated gifted children, however, the role of WM has not yet been adequately investigated. To the best of my knowledge, there is only one study that addressed this issue (Okamoto, Curtis, Jabagchourian, & Weckbacher, 2006). Although this study did not find teacher-nominated gifted children to have a higher WM capacity than the norm, it has to be acknowlegded that the study lacked a non-gifted control group and used only one unstandardized measure of WM. Thus, no valid conclusion regarding this issue can be drawn. Moreover, from a theoretical point of view, it is still likely to assume that teacher-nominated gifted children are characterized by high WM capacity (see 1.1.4 ‘Characteristics of teacher-nominated gifted children’).

Based on the assumption that high WM capacity represents an important characteristic of teacher-nominated gifted children, it would be reasonable to provide these children with promotion or learning offers that particularly challenge WM resources. Specifically, respective learning offers may stimulate complex learning processes that particularly build upon working memory processes such as, for instance, multiperspective reasoning or inferential thinking (e.g., Zydney, 2010), thereby also further developing students’ WM capacity. This reasoning is in line with ATI research claiming that an instructional design should be matched to a learner's particular prerequisites in order to be optimally beneficial (Cronbach & Snow, 1977). WM resources, which are herein considered as the learner's respective prerequisites, are associated with various executive control processes (e.g., planning and conducting of goal-directed behavior, focusing on relevant information; Baddeley, 2007; 2012; Miyake et al., 2000; Oberauer, 2009). Such executive control processes are particularly demanded in self-directed learning offers, that is, learning offers that require from learners to autonomously structure and control their learning process. Nowadays such self-directed learning settings can increasingly be found among digital learning technologies such as, for instance, instructional hypermedia environments (e.g., Amadieu & Salmerón, 2014; ChanLin, 2008). Apart from their high amount of executive control requirements, hypermedia environments provide an innovative and interactive learning approach that can be even more beneficial for learners than other, more traditional learning settings (e.g., Jacobson et al., 1996). Therefore, appropriately designed hypermedia environments might be optimal for learners who are characterized by high WM capacity and can, thus, cope with the executive control requirements in hypermedia environments. In the third part of the introduction (1.3), hypermedia environments will be described in more detail, thereby also pointing out their relation with WM capacity.

1.3 Hypermedia Environments

Hypermedia environments originate from hypertext systems, which were introduced in the 1960s by Ted Nelson (e.g., Nelson, 1965). Hypertexts are information systems that contain multiple information nodes that are interconnected in a nonlinear, network-like structure (Scheiter & Gerjets, 2007). Whereas hypertext includes mainly textual information that can be supplemented with static media such as graphs, diagrams, or tables (Tolhurst, 1995), hypermedia is characterized by information that can also be displayed in terms of dynamic-active media such as animation, video, or audio (Scheiter & Gerjets, 2007). Thus, hypermedia can be described as a nonlinear network that comprises differently linked information in form of texts, graphics, sounds, animations, or videos (see Figure 2). The presentation of several representational formats such as texts, sounds, videos, or animations can also be found in multimedia. However, contrary to hypermedia, multimedia is often characterized by a linear information access (e.g., e-books containing texts, pictures, animations, videos, etc.). Broadly speaking, hypermedia can be considered as an intersection of multimedia and hypertext. A typical example of a huge hypermedia system is the World Wide Web, which allows users to access multimedia information from all over the world. This information is linked together in almost unlimited ways.

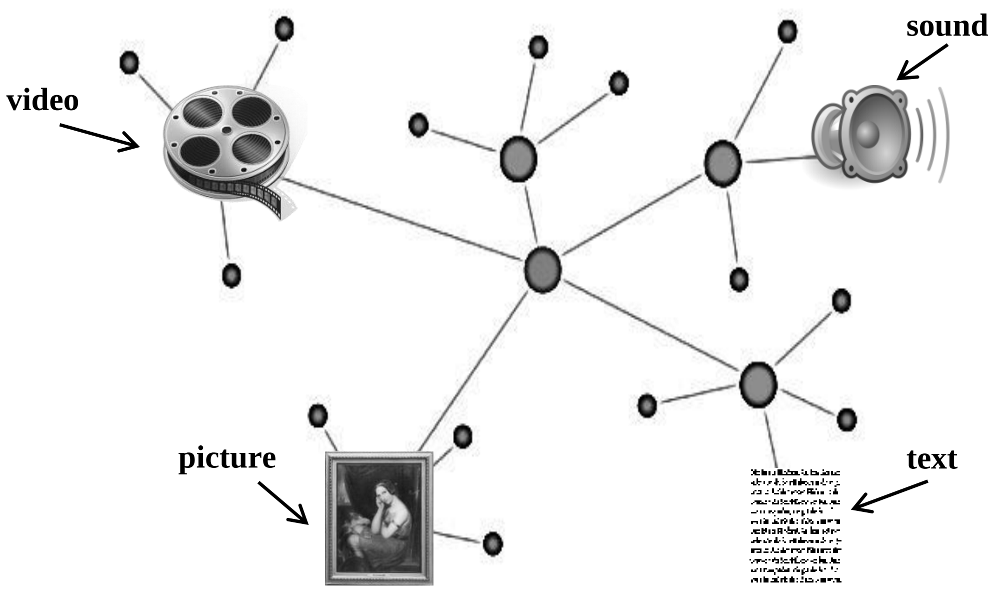

Figure 2. Nonlinear network with differently linked multimedia information (e.g., text, picture, sound, video).

Generally, there are two hypermedia structures that can be differentiated: hierarchical and networked (DeStefano & LeFevre, 2007). More precisely, the hierarchical structure is characterized by an initial single node or home page, which has links leading to subordinate nodes. The interconnection of these nodes can be described as a tree structure with broader topics at higher levels and subordinate topics at lower levels. The networked hypermedia structure, by contrast, is characterized by non-sequential, associative links that are used to relate semantically similar concepts in the environment and to point out interrelationships between the main topics. While hierarchical interconnections represent an information structure, networked interconnections represent semantic relations. Often, a combination of both structures, which then form a hybrid structure, can be found (Lowe & Hall, 1999).

Compared to system-controlled or linear computer environments, in which learners are rather passive than active recipients of the learning materials, hypermedia environments emphasize the self-directed exploration of information. Due to features including nonlinearity, interactivity, and flexibility, hypermedia environments are characterized by a high level of learner control (Scheiter & Gerjets, 2007). This means that learners are allowed to determine the order in which they would like to access information. Moreover, they can decide about the content they want to receive as well as about the representational format (e.g., text or video), in which a content should be displayed. Cognitive psychologists have ascribed great potential to this nonlinear, network-like organization of information for learning (e.g., Jonassen, 1991). In the following, four respective cognitive theories will be presented and embedded within the context of hypermedia learning (1.3.1). Subsequently, further potentials of hypermedia environments for learning will be theoretically and empirically outlined (1.3.2).

1.3.1 Cognitive theories and hypermedia learning

According to cognitive psychology, learning is defined as an active, individual process that incorporates the reorganization of knowledge structures (e.g., Rumelhart, 1981; Jonassen, 1988). Specifically, during learning new information is related to existing information so that new knowledge structures are created. Thereby, learning is assumed to be most successful when several associations between new and existing information are built. However, how knowledge is exactly structured varies among different cognitive theories. Hereinafter, four cognitive theories, namely schema theory (cf. Jonassen, 1988), dual coding theory (Paivio, 1991), the construction-integration model (van Dijk & Kintsch, 1983; Kintsch, 1988), and cognitive flexibility theory (Jacobson & Spiro, 1995; Spiro & Jehng, 1990) will be described in more detail and related to hypermedia learning. Specifically, these four theories focus on different design aspects of hypermedia environments (e.g., network-like structure or multimedia illustrated information) that may benefit learning with hypermedia environments. Note that there are also cognitive theories, such as cognitive load theory (CLT; Sweller, 1988), that rather emphasize potential disadvantages of a hypermedia design for learning. This issue, however, will be discussed later (see 1.3.3).

Schema theory

Schema theory (e.g., Jonassen, 1988; Schank & Abelson, 1977; Pearson, 1992) ascribes high potential to the network-like design structure of hypermedia environments, which is assumed to reflect knowledge structures in the human mind and thus to facilitate learning and processing of information. In general, schema theory describes learning as the accumulation and organization of various knowledge structures. These knowledge structures are all stored in human’s semantic memory. They can consist of an object, an idea, or an experience and are each linked to further knowledge structures. These arrangements of networked knowledge structures in mind are referred to as schemas. As everyone has different experiences, ideas, or encounters, people differ in their acquired schemas and their attributes associated with a respective schema. A person’s schema for a car, for instance, might comprise attributes such as vehicle, engine, wheels, and so on. The attributes (e.g., engine, wheels) for one schema (e.g., car) can additionally be associated with various other schemas. For example, wheels can also be associated with the concept of a bicycle. These associations between different schemas are assumed to facilitate the combination of ideas or to draw inferences and conclusions. Taken together, all schemas associated by their overlapping attributes form a huge network of knowledge, namely a semantic network.

Schema theory defines learning as an integration of new information into existing schemas or as the creation of new schemas. Thereby it is assumed that the new information will be learned best, if many associations relate existing knowledge to new knowledge. More precisely, new information is first received and interpreted. Subsequently, this information is assimilated and accommodated into existing schemas. This finally results in a reorganization of the whole schema network (Anderson & Pearson, 1984). Schema theory assumes that during learning the learner’s knowledge structure begins to resemble the one of the instructor. Learning can hence be described as a mapping of the subject matter knowledge provided by the instructor onto the learner’s knowledge structure.

As already mentioned above, hypermedia systems are considered to simulate the assumed schema-based knowledge structure in the human mind. Specifically, the various information nodes that are interconnected by several links build a network of information that mirrors the one assumed for human memory (Jonassen, 1991; Jonassen & Grabinger, 1990).

Whereas hypermedia information nodes represent the schemas, the hypermedia links are supposed to represent the semantic associations between the schemas. According to Jonassen (1988), a learning environment (i.e., a hypermedia environment) that resembles the way information is processed in human memory facilitates learning. Additionally, Jonassen (1991) suggests hypermedia structures to reflect the knowledge structures of experts. Therefore, a hypermedia environment that represents an expert's knowledge structure can map more directly onto the learner's cognitive schema structure during learning than otherwise illustrated materials. However, researchers have argued that mental structures are more complex and contain much more information than a hypermedia system and thus criticize this oversimplification (Tergan, 1997; Whalley, 1990). Moreover, a study, which showed that a hypermedia design that was based on an expert's knowledge representation was not better for learning than other ways of knowledge representations, also empirically weakened the argument (Jonassen & Wang, 1993). Thus, to what extent the network-like structure of hypermedia environments actually stimulates better processing and learning due to its similarity with human knowledge structures remains to be discussed.

Dual coding theory

Another cognitive theory that ascribes great potential to hypermedia systems is Paivio's dual coding theory (DCT; Paivio, 1991; Sadoski & Paivio, 2001). The DCT mainly refers to multimedia learning (Mayer, 2005) but can also be used to describe one beneficial design aspect of hypermedia environments, namely the multimedia presentation of information. Specifically, the DCT assumes learners to process verbal and nonverbal information in different representational systems, namely a verbal system and a nonverbal system. Whereas the verbal system deals with language, the nonverbal system processes knowledge about objects, events, and also affects. As the nonverbal system (rather) generates and represents images (as compared to verbal information), it is also referred to as the imagery system. Both systems are independent, meaning that each system alone but also both systems together can be activated during information processing. Moreover, one system can initiate the other. Importantly, individuals are supposed to learn better when information is processed in both systems. The fact is that this dual coding of information, namely verbally and nonverbally, is considered to be additive. That is to say, if information is processed through two cognitive channels, the learner creates more cognitive trails to the information and thus elaborates information deeper. This is suggested to result in better recall of the information. Hypermedia environments facilitate dual coding as they provide verbal materials (e.g., texts) as well as pictorial materials (e.g., pictures or animations) of the same content.

Therefore, learning with hypermedia is assumed to be more effective than learning with single media information (Peng & Fitzgerald, 2006; Yildirim, Ozden, & Aksu, 2001).

Construction-integration model

The construction-integration model (CIM; van Dijk & Kintsch, 1983; Kintsch, 1988) ascribes great potential to the nonlinear information structure in hypermedia environments. The CIM assumes this nonlinear structure to particularly support active learning, which in turn should lead to deeper elaboration of the learning materials. Originally, the CIM is a theory of text processing and comprehension. Specifically, it suggests a two-stage process of text comprehension: knowledge construction and knowledge integration. The first process is concerned with the construction of a propositional representation of the semantic content (i.e., a text base). Importantly, the construction of this mental representation is solely based on the factual information explicitly stated in the text. Subsequently, the second process involves the integration of this factual information with additional information sources such as prior knowledge or mental imagery. To this end, a situation model is constructed. The construction of the situation model is further influenced by the text coherence perceived by the readers, that is, their ability to understand relations between ideas in the text and to draw respective inferences. These processes associated with the construction of a situation model (i.e., integration of prior knowledge, text coherence) are highly necessary to reach a deep understanding of the new information. In order to build such a situation model, however, active learning is required. As hypermedia environments are assumed to support active learning, they should facilitate the construction of a situation model and thus enable deeper understanding and learning (Scheiter & Gerjets, 2007; Shapiro & Niederhauser, 2004). More precisely, the nonlinear presentation of information in hypermedia environments forces learners to identify important relationships between information nodes by themselves. Moreover, learners have to evaluate all information with regard to their relevance for the learning goal (Patterson, 2000). This is assumed to lead to deep elaboration processes. By contrast, in linearly structured materials (e.g., textbooks) the argumentative structure of a topic is normally provided. These environments are thus rather associated with passive than with active learning.

However, whether hypermedia instruction unconditionally encourages active engagement with the topic is doubtful. Indeed, early studies on hypertext have shown that these may also be used passively which consequently leads to less educational benefits (Meyrowitz, 1986). Moreover, instead of stimulating active construction and integration of knowledge, hypermedia environments might also result in a lack of coherence for learners with insufficient cognitive resources. More precisely, the fragmentation of information might strongly reduce coherence between to-be-integrated information so that the construction and integration of knowledge might rather be impaired. This in turn can result in lower comprehension and learning (McNamara & Kintsch, 1996; Shapiro & Niederhauser, 2004). To conclude, the potential benefits that the CIM ascribes to hypermedia environments, namely that the nonlinear presentation of information stimulates active learning as learners have to draw inferences or have to evaluate the relevance of the materials, might only apply to learners with specific prerequisites such as high motivation (i.e., willingness to engage in active learning) or high cognitive resources (to avoid mental overload due to the fragmentation of information).

Cognitive flexibility theory

Cognitive flexibility theory (CFT; Jacobson & Spiro, 1995; Spiro & Jehng, 1990) is a theoretical framework that emphasizes the beneficial effect of hypermedia instruction for complex learning domains. Specifically, CFT assumes that the network-like structure of hypermedia environments is ideally suited to stimulate complex learning processes such as, for instance, multiperspective reasoning (cf. Zydney, 2010). According to CFT, traditional learning materials that provide information in a linear sequence are not appropriate to represent the complexity of so-called multifaceted knowledge domains (Spiro, Feltovich, Jacobson, & Coulson, 1992). These domains require learners to take multiple viewpoints on the current topic into consideration simultaneously (cf. Fitzgerald, Wilson, & Semrau, 1997; Zydney, 2010). In a study by Zydney (2010), for example, students had to consider divergent perspectives on a complex air pollution problem (e.g., environmental, economic, legal, and engineering perspectives). In a study by Lowrey and Kim (2009), learners were required to deal with multiple viewpoints on the issue of cloning. The materials in both studies were displayed by means of a hypermedia structure, which did not only facilitate the association of different conceptual perspectives but also supported learners to derive a balanced conclusion about the topic.

In order to adequately display the complexity of such multifaceted knowledge domains, CFT makes suggestions about how to design respective computer-based learning environments. Important design principles are, for instance, to provide multiple perspectives for domain exploration, to use case-based instruction to illustrate the multiple perspectives of the content, or to highlight interconnections among different domain concepts. In this vein, hypermedia environments are considered to be eminently suitable for representing knowledge in a multiperspective way because their network-like organization of information can better reflect the multifaceted nature of such complex domains than a linear organization (Scheiter & Gerjets, 2007). Specifically, the network-like organization allows for examining a topic from multiple perspectives by revisiting the same contents in a variety of different contexts (Jacobson & Spiro, 1995). This “criss-crossing” of the conceptual landscape (i.e., revisiting the same contents in a variety of different contexts) in multiperspective hypermedia environments (i.e., hypermedia environments designed according to CFT principles; cf. Lima, Koehler, & Spiro, 2002) is assumed to support learners to develop a flexible understanding of the multifaceted subject matter. This should help to avoid inapt oversimplifications, and to facilitate the construction of a proper mental representation of multifaceted topics (Jacobson & Spiro, 1995; Spiro & Jehng, 1990). Furthermore, these flexible cognitive structures should enable learners to transfer acquired knowledge elements to novel problem contexts (Spiro et al., 1992).

McVee, Dunsmore, and Gavelek (2005) supposed that CFT is particularly well-suited for the theoretical design of innovative technologies (e.g., instructional hypermedia environments), which are nowadays increasingly advocated in the educational context. There are, however, studies that did not find CFT-based environments to be more effective for learning than linear environments (e.g., Balcytiene, 1999; Lowrey & Kim, 2009; Niederhauser, Reynolds, Salmen, & Skolmoski, 2000). This might be due to the fact that these environments are generally quite demanding with regard to cognitive and metacognitive resources (e.g., Lowrey & Kim, 2009; Niederhauser et al., 2000). To conclude, the potential benefit that CFT ascribes to hypermedia environments, namely that the nonlinear structure better stimulates and supports complex learning processes, might rather apply to learners with high cognitive and metacognitive resources. Accordingly, CFT claims that hypermedia instruction should primarily be used for advanced learners who particularly aim to master a complex knowledge domain (Spiro & Jehng, 1990).

Taken together, the four cognitive theories (i.e., schema theory, DCT, CIM, CFT) focus on different design aspects of hypermedia environments and how these aspects may benefit learning. Specifically, DCT focuses on the multimedia presentation of information and assumes this presentation to facilitate learning as it enables information processing in two different coding systems. By contrast, schema theory, CIM, and CFT all focus on the nonlinear, network-like structure of hypermedia environments. However, they all ascribe different potentials to this structure. Whereas schema theory states that the network-like structure resembles the knowledge structure of the mind, which is assumed to facilitate processing and learning of information, CIM suggests that this nonlinear structure optimally stimulates active learning. Finally, CFT considers the nonlinear, network-like structure to better stimulate and support complex learning processes than a linear structure. Importantly, CIM and CFT limit these beneficial affects to advanced learners (i.e., learners with high cognitive abilities and/or high motivation). With regard to the present dissertation, thus, the implementation of hypermedia environments for students with high cognitive potential (i.e., high WM capacity) seems to be reasonable as it provides several benefits for learning (i.e., better processing of information due to multimedia materials, stimulation of active learning and deeper elaboration, stimulation of complex learning processes).

1.3.2 Theoretical and empirical potential of hypermedia environments

In addition to the benefits ascribed to hypermedia by the cognitive theories, hypermedia environments hold further promise for learning (Scheiter & Gerjets, 2007). In this vein, for instance, hypermedia environments are considered to improve learners' interest and motivation. As hypermedia environments accompany high learner control, learners are allowed to make their own decisions during the learning process. Consequently, they experience control over the learning process, which, in turn, is supposed to foster feelings of self-efficacy and self-determination (Snow, 1980). In line with this, Becker and Dwyer (1994) found students to experience a higher sense of control and also an increased level of intrinsic motivation after having used a hypertext. Liu (1998; see also Liu & Pedersen, 1998) also found an increased motivation as well as an increased creativity due to the engagement with hypermedia in a sample of elementary school children. Another potential of learner-controlled hypermedia environments can be seen in the accommodation of different learner styles, namely that hypermedia enables adaptive instruction that is based on the learners' needs and abilities. Specifically, as learners can autonomously decide which information they want to process and how they want to further sequence, they can organize the information acquisition depending on their individual needs (Barab, Bowdish, Young, & Owen 1996). Furthermore, it has been claimed that the high level of learner control in hypermedia environments fosters students' self-regulation abilities during the learning process (Azevedo, 2005). More precisely, by exploring such a self-directed learning environment, learners have to apply self-regulatory skills, such as setting goals as well as monitoring, regulating, and controlling cognition, motivation, and behavior to reach these goals, in order to benefit from the respective learning setting (Winne & Perry, 2000).

A lot of research has been conducted to examine the educational effectiveness of hypermedia instruction compared to other forms of instruction (e.g., Eveland, Cortese, Park, & Dunwoody, 2004; Hartley, 2001; Jacobson & Spiro, 1995; Lanzilotti & Roselli, 2007;

Niederhauser et al., 2000; Rehbein, Hinostroza, Ripoll, & Alister, 2002; Salmerón & García, 2012; Yeh & Lehman, 2001; Yildirim et al., 2001). In their comprehensive review, Chen and Rada (1996) examined 23 studies on the effectiveness of hypermedia instruction. In conclusion, these studies failed to show that hypermedia fulfilled the high effectiveness expectations. Moreover, Dillon and Gabbard (1998) examined 30 studies on the effectiveness of hypermedia and came to the conclusion that the educational benefits of hypermedia were limited and depended, for instance, on the specific learning task as well as on the learner’s ability and learning style. In line with this, several studies demonstrated that for specific learning tasks, hypermedia instruction was indeed superior to linear instruction (e.g., Eveland et al., 2004; Jacobson & Spiro, 1995; Rehbein et al., 2002; Salmerón & García, 2012). Salmerón and García (2012), for example, investigated in a sample of sixth-graders how successful the children explored information in a hypermedia environment as compared to an environment in which the same information was presented in a linear sequence. They demonstrated that children were more encouraged by the hypermedia environment to explore information that had to be related and integrated from different information nodes than by the linearly structured material. However, when learners were required to extract information that was stated in a single node, hypermedia instruction were not superior to linear instruction. In another study, Jacobson and Spiro (1995) investigated the potential of hypermedia instruction for the acquisition of complex and ill-structured knowledge. They used three instructional conditions with every condition displaying another degree of hypermedia features (i.e., no hypermedia features, minimal hypermedia features, full hypermedia features). Their results showed that students who used the full hypermedia instruction performed better than the other students for superior knowledge transfer. The other students, however, performed better when factual recall was demanded. Thus, in line with the idea of CFT (e.g., Jacobson & Spiro, 1995), hypermedia environments seem to be more beneficial than linear instructions for complex task demands such as knowledge transfer or the integration of information from different nodes. However, with regard to other learning goals, such as factual recall or extraction of information stated in a single node, linear instruction seems to be superior (Eveland, et al., 2004; Jacobson & Spiro, 1995; Rehbein et al., 2002; Salmerón & García, 2012).

Taken together, the majority of studies did not find hypermedia instruction to be generally more beneficial than more traditional, linear instruction (Barab, Young, & Wang, 1999; Hartley, 2001; Lee & Tedder, 2003; McDonald & Stevenson, 1996; Niederhauser et al., 2000; Schwartz, Andersen, Hong, Howard, & McGee, 2004). These somehow disillusioning results regarding the envisioned benefits of hypermedia learning engender the assumption that hypermedia environments also have their drawbacks. In the next section, these drawbacks will be specified in more detail.

1.3.3 Drawbacks of hypermedia environments

Hypermedia environments are assumed to provoke several usability problems such as disorientation, distraction, split attention, or cognitive overload (cf. Scheiter & Gerjets, 2007). Unfortunately, these usability problems can easily overshadow the benefits of hypermedia environments. For instance, one of the most beneficial features of hypermedia, namely the freedom of exploration, can concurrently lead to usability problems such as disorientation and distraction. In the following section, the four usability problems (i.e., disorientation, distraction, split attention, and cognitive overload) will be described more precisely.

Disorientation can be defined as a problem that occurs when learners are lost in the hypermedia environment, that is, when they do not know where they actually are in the network, what they want to explore next, and how to find the information intended to be explored (Foss, 1989). Frequent reference is made to this phenomenon as ‘lost in hyperspace’ (e.g., Astleitner & Leutner, 1995; Conklin, 1987; McAleese, 1989). Foss (1989) argues that the disorientation problem results from the large, complex, and partly confusing data structure in hypermedia environments in combination with the navigational freedom. In this vein, it has been shown that fewer links and consequently fewer navigational choices in a hypermedia environment lead to better learning outcomes (Paolucci, 1998; Zhu, 1999). Generally, empirical studies found learners who experienced a higher degree of disorientation to show lower achievement (Beasley & Waugh, 1996; Edwards & Hardman, 1989). Therefore, researchers aim to find technological solutions such as navigational tools or structural overviews to counteract the disorientation problem (Dias, Gomes, & Correia, 1999; Salmerón, Cañas, Kintsch, & Fajardo, 2005).

Distraction can be defined as a problem that occurs when learners do not address the pre-specified learning goal but follow information based on their specific interest. Thereby, the interest can change according to the currently explored context (Scheiter & Gerjets, 2007). However, whether interest-guided browsing is evaluated as negative or positive depends on the general learning goal. For instance, in case of a specific learning goal, which demands from learners to briskly identify some specific information, interest-guided exploration might distract learners from pursuing this goal (Foss, 1989). In that case, distraction can be labeled as a problem. Scheiter, Gerjets, and Heise (2014) investigated the effect of goal competition on problem-solving performance in a hypermedia environment. They found that the presence of task-irrelevant information that was related to a pending goal (i.e., a learning goal that learners were asked to pursue later) impaired problem solving performance, however, only when students worked on simple problems, but not when they worked on complex problems. With regard to broad learning goals, by contrast, in order to get a general understanding of the topic, interest driven exploration might be less harmful. In this sense, Hammond (1993) claimed that interest-guided browsing can lead to unintentional acquisition of knowledge (‘serendipity effect’).

Split attention can be defined as a problem that results from the fragmentation of information into smaller hyperlinked units (Whalley, 1990). In order to determine an appropriate structure to the information and to perceive relations between information units, learners have to integrate information from multiple sources. In doing so, learners must split or divide their attention between these sources (i.e., split-attention effect; cf. Chandler & Sweller, 1992). The cognitive integration of these split information requires a high degree of cognitive resources from learners. If learners have not sufficient resources available (see cognitive overload in the next paragraph; Sweller, 1988), this information fragmentation might strongly reduce text coherence, which can in turn impede text comprehension processes and learning (see also 1.3.1, CIM; McNamara & Kintsch, 1996; van Dijk & Kintsch, 1983; Shapiro & Niederhauser, 2004).

Finally, cognitive overload can be defined as a problem that results from the amount of information provided by hypermedia environments as well as from the freedom of navigation in such environments. More precisely, learners might be overwhelmed by the richness of information so that not all learners might be able to evaluate all information with regard to its current relevance in order to limit the amount of information to be processed. Instead, these learners try to handle all information at once which can finally result in cognitive overload. Furthermore, the navigational freedom requires from learners to decide which information to select or how to further sequence in the environment. These navigational demands are associated with metacognitive or executive skills that claim for additional effort and concentration, thus, for additional cognitive resources. Consequently, less cognitive resources are available for comprehension and learning processes (Mayes, Kibby, & Anderson, 1990). This explanation stems from cognitive load theory (CLT; Sweller, 1988), which assumes a causal relation between the instructional design, cognitive abilities, and the resulting cognitive load, which in turn impacts comprehension and learning. Specifically, if the cognitive load is too high – due to an unsuitable instructional design or low cognitive abilities –, learning and comprehension processes are assumed to be hampered.

Accordingly, Niederhauser et al. (2000) found in their hypertext study that the use of an additional navigational feature (to compare and contrast pages) rather hampered than supported students' performance. They suggested that this additional navigational feature highly loaded on cognitive resources so that these resources were no longer available to process and understand the content of the learning environment.

It has already been claimed that learners with more advanced learning prerequisites might suffer less from the usability problems that can occur during hypermedia learning (i.e., distraction, disorientation, split attention, cognitive overload). In this vein, for instance, hypermedia instruction has been found to be more beneficial for learners with higher prior knowledge, better self-regulatory skills, or sophisticated epistemic beliefs (Azevedo, 2005; Bendixen & Hartley, 2003; Dillon, 1996; Jacobson et al., 1996; Kammerer, Bråten, Gerjets, & Strømsø, 2013; Lawless & Kulikowich, 1996; Lowrey & Kim, 2009; Salmerón et al., 2005). For example, Salmerón et al. (2005) reported that reading a low coherent hypertext did only impair learning for low prior knowledge students but not for high prior knowledge students. Kammerer and colleagues (2013) investigated the impact of students' internet-specific epistemic beliefs on their evaluation of information sources when searching the Web on a complex, multifaceted topic. They reported that a naïve epistemic trust in the Web restricted source evaluation in that students holding respective beliefs underestimated the necessity to actively engage in source evaluation, which resulted in a less balanced representation of the complex issue. By contrast, students with more sophisticated epistemic beliefs (i.e., having doubts about the credibility of the Web) engaged more in source evaluation, which was assumed to be necessary to construct a complete representation of a complex topic. As will be argued in the following section, another, but so far less attended learning prerequisite that might help to counteract the usability problems in hypermedia environments is WM capacity.

1.3.4 Hypermedia and working memory

As already described above (1.3.3), hypermedia environments are quite demanding with regard to cognitive resources and can more easily result in a cognitive overload for learners than, for instance, linear environments (Lowrey & Kim, 2009; Niederhauser et al., 2000). More specifically, cognitive challenges such as the navigational freedom require learners to decide on link selection, to divide attention between co-occurring information, to identify relevant information while inhibiting irrelevant but seductive information, to resolve coherence gaps, to flexibly restructure their knowledge, or to maintain a current goal (cf. Niederhauser et al., 2000; Scheiter & Gerjets, 2007; Whalley, 1990). In addition, learners are required to process large amounts of information, to integrate different kinds of information, and to keep the results in mind during subsequent processing steps (cf. Ericsson & Kintsch, 1995). These cognitive demands involve a high degree of information processing and executive control. As has been outline above (see 1.2), a cognitive construct that, on the one hand, is strongly associated with information processing activities and, on the other hand, represents an important executive control system is WM (e.g., Baddeley, 2002; Engle et al., 1999a; Oberauer, 2009). Therefore, it is likely that WM capacity is related to hypermedia learning. Specifically, learners with high WM resources should be better able to cope with the cognitive demands in hypermedia environments and to thus benefit more from hypermedia instruction in terms of comprehension and learning than learners with low WM resources.

In line with this reasoning, DeStefano and LeFevre (2007) concluded from their review of 38 studies about cognitive load in hypertext reading that WM theoretically represents an important construct for explaining performance differences during hypermedia learning. Accordingly, empirical research in the field of hypermedia instruction provides first evidence for the impact of WM capacity on hypermedia learning (Lee & Tedder, 2003; Pazzaglia, Toso, & Cacciamani, 2008; Tsianos, Germanakos, Lekkas, Mourlas, & Samaras, 2010). Pazzaglia and colleagues (2008), for instance, investigated the association of different WM functions (cf. multiple-component model of WM by Baddeley & Logie, 1999; see 1.2.1) with performance during hypermedia learning in a sample of sixth-graders. They found that both visuospatial WM and verbal WM influenced hypermedia learning. Furthermore, Tsianos and colleagues (2010) examined the role of WM capacity on performance in a personally adapted educational hypermedia environment as compared to a standard non-personalized hypermedia environment. The authors reported that students with high WM capacity performed generally better than students with low WM capacity independent of whether they worked through a personally adapted hypermedia environment or through a standard hypermedia environment.

To conclude, both studies (Pazzaglia et al., 2008; Tsianos et al., 2010) emphasize the importance of WM for hypermedia instruction. Still, they only focused on the role of WM capacity in hypermedia environments without concurrently comparing it to the role of WM capacity in linearly structured environments. Thus, whether WM capacity represents a necessary resource to benefit more from hypermedia instruction than from linear instruction cannot be inferred from these findings. This question, however, was addressed in a study by Lee and Tedder (2003). Specifically, they investigated the effect of three different computerized texts (traditional linear text, hierarchically structured hypertext, networked hypertext) on recall performance based on learners' WM capacity. Although they demonstrated that students with high WM capacity had a significantly better recall than students with low WM capacity, they did not find a significant interaction effect with the three conditions in that students with high WM capacity would benefit more from the hypertext than from the traditional text. Instead, they found students with high WM capacity to equally benefit from all conditions. Students with low WM capacity tended to benefit most from the traditional text. Nevertheless, this effect was not significant. Note, however, that Lee and Tedder (2003) used text recall as a performance measure. As already discussed above (1.3.2), hypermedia instruction does not seem to particularly support recall performance as compared to traditional, linear environments (e.g., Eveland, et al., 2004), and therefore, the results of Lee and Tedder (2003) are not surprising. Instead, and also in line with CFT (e.g., Jacobson & Spiro, 1995), hypermedia environments seem to be more beneficial than linear instructions for complex task demands such as the integration of different ideas or knowledge transfer. Thus, whether WM capacity represents a necessary learning characteristic to benefit more from hypermedia instruction in terms of complex task demands as compared to linear instruction has not been empirically investigated yet. Therefore, one goal of the present dissertation is to address this issue.

Beyond that, the present dissertation further aims to uncover which underlying processes during hypermedia learning might be positively affected by WM capacity. In this vein, the role of navigational processes during hypermedia learning is envisioned, specifically since navigational processing demands do not only represent a characteristic feature of hypermedia environments, but have also been found to explain individual performance differences during hypermedia learning (e.g., Lawless, Brown, Mills, & Mayall, 2003; Naumann, Richter, Christmann, & Groeben, 2008; Salmerón & García, 2011). Thus, in the final section of this part, the role of navigation in hypermedia environments and its relation to WM capacity will be discussed.

1.3.5 Hypermedia, navigation, and working memory

Navigation is one of the most important issues in hypermedia environments as the way in which users explore the contained information has an impact on comprehension and learning (e.g., Lawless et al., 2003; Naumann et al., 2008). Unfortunately, not all navigational choices and behaviors are assumed to maximize comprehension and learning. Accordingly, several studies investigated the effectiveness of navigational behaviors to find out what kind of navigational processing best supports the exploration of hierarchical or networked hypermedia environments (e.g., Lawless et al., 2003; Naumann et al., 2008; Richter, Naumann, Brunner, & Christmann, 2005; Puntambekar & Goldstein, 2007; Salmerón &

García, 2011; Salmerón, Kintsch, & Cañas, 2006). In this vein, for instance, Richter and colleagues (2005) reported that linear sequencing and less backtracking behavior (clicking backwards) were indicators of a systematic navigational behavior and of fewer orientation problems. These navigational behaviors were, in turn, also related to better learning outcomes. Furthermore, Salmerón, Baccino, Cañas, Madrid, and Fajardo (2009) as well as Salmerón and García (2011) investigated the influence of graphical overviews, which represented the hierarchical hypertext structure, on hypertext processing. They found that initial processing of the overview most benefitted comprehension of the hypertext. Additionally, choosing a coherent navigation path (i.e., subsequently navigating through semantically related pages) and focusing on task-relevant pages were also associated with better comprehension and learning (Dimopolous & Asimakopoulos, 2009; Klois, Segers, & Verhoeven, 2013; Naumann et al., 2008; Puntambekar & Goldstein, 2007; Rezende & de Souza Barros, 2008; Salmerón & García, 2011; Salmerón et al., 2006).

Furthermore, some studies also focused on learners' navigational profiles during hypermedia exploration and their relation to comprehension and learning (Barab, Bowdish, & Lawless, 1997; Lawless & Brown, 1997; Lawless et al., 2003; Lawless & Kulikowich, 1996; Lawless & Kulikowich, 1998; Rezende & de Souza Barros, 2008; Scheiter, Gerjets, Vollmann, & Catrambone, 2009). In those studies, three navigational profiles during hypermedia exploration have been repeatedly found: (1) knowledge seekers, (2) feature explorers, and (3) apathetic hypertext users (Barab et al., 1997; Lawless & Kulikowich, 1996; Lawless & Kulikowich, 1998). Whereas knowledge seekers can be described as users that mainly pursue information related to the content and the task, feature explorers spend most time interacting with special features of a hypermedia environment (e.g., movies, animations, graphics). Apathetic hypertext users, by contrast, seem to be unmotivated to engage in hypermedia exploration at all. Unsurprisingly, knowledge seekers showed a higher learning performance than feature explorers and apathetic hypertext users (Lawless & Kulikowich, 1996; Lawless & Kulikowich, 1998).

Taken together, empirical research on navigational behaviors in the context of hypermedia learning reveals on the one hand, that some navigational behaviors are more effective than others and on the other hand, that not all learners apply effective navigational behaviors (e.g., Lawless & Kulikowich, 1996). Indeed, effectively navigating a hypermedia environment demands high cognitive and metacognitive resources from learners (Fitzgerald, 1998). Therefore, only learners with respectively high resources might be able to engage in effective navigation. In line with this, previous research related a variety of learner characteristics such as prior knowledge, web experience, self-efficacy, metacognitive skills, or situational interest to navigational behaviors in hypermedia settings (Barab et al., 1997; Dimopoulos & Asimakopoulos, 2009; Lawless & Kulikowich, 1996; Lawless & Kulikowich, 1998; Lawless et al., 2003; Lawless, Mills, & Brown, 2002; MaKinster, Beghetto, & Plucker, 2002; Tu, Shih, & Tsai, 2008). All of these variables have been shown to positively impact hypermedia navigation with prior knowledge being the most influential variable so far (e.g., Carmel, Crawford, & Chen, 1992; Lawless & Kulikowich, 1996; Lawless et al., 2003).

The construct of WM, however, has so far received less attention in the context of hypermedia navigation. One study by Naumann and colleagues (2008) (indirectly) related WM capacity to navigational behaviors in a hypertext setting. The authors reported that students with higher WM capacity benefitted more from a hypertext strategy training in terms of their learning outcome than students with lower WM capacity and that this effect was partially mediated by task-related navigational behaviors. Nevertheless, the direct relation of WM capacity to navigational behaviors in hypermedia environments has not yet been examined, although WM resources are theoretically likely to be involved in a variety of navigational processes during hypermedia learning. McDonald and Stevenson (1996), for instance, argue that focusing on the task as well as finding and locating relevant information heavily loads on WM resources. Moreover, navigational processes such as inhibiting irrelevant but seductive information, dividing attention between co-occurring information, or deciding on link selection involve a high degree of executive control and can therefore easily be related to the construct of WM (cf. Niederhauser et al., 2000; Scheiter & Gerjets, 2007). However, whether high WM capacity enables more effective navigation in hypermedia environments in terms of comprehension and learning has not been addressed yet. Therefore, the present dissertation aims to examine the relationship between WM capacity, navigational processing, as well as comprehension and learning in a hypermedia environment. Next, the specific aims of each study comprised in this dissertation will be describe in more detail.

1.4 Research Questions of the Present Dissertation

The present dissertation focuses on the interplay of giftedness, WM capacity, and hypermedia learning. Specifically, it first explores whether WM capacity represents a crucial characteristic of teacher-nominated gifted children (fourth-graders) and second whether learning offers that take advantage of high WM resources, such as hypermedia environments, are thus particularly beneficial for these children. Third, it considers navigational processes during hypermedia exploration to uncover whether these processes might underlie and hence explain the relation between WM capacity and learning in hypermedia environments.

Concerning the first research question, the present dissertation aims to investigate the learning prerequisites of teacher-nominated gifted children. Although there is already a vast amount of research concerning the characteristics of teacher-nominated gifted children (e.g., Endepohls-Ulpe & Ruf, 2005; Hernández-Torrano et al., 2013), one important cognitive construct has not been considered in this context so far, namely WM. As theoretically discussed above (see 1.1.4), however, WM is likely to represent an essential characteristic of teacher-nominated gifted students. Therefore, the research question as to whether WM actually represents a crucial characteristic of teacher-nominated gifted children, even beyond intelligence, is addressed in the first study (Research Question 1). Specifically, a group of teacher-nominated fourth-graders will be compared to a group of non-nominated fourth-graders in terms of their WM capacity, their STM capacity, and their fluid intelligence (further details will be given below).

Concerning the second research question, the present dissertation aims to investigate whether learning offers that are particularly matched to the children’s prerequisites are more beneficial than less adapted learning offers in terms of comprehension and learning. Specifically, assuming that the findings of Study 1 reveal teacher-nominated gifted children to exhibit particularly high WM capacities, appropriate promotion or learning offers should take advantage of these WM resources (i.e., executive control and information processing). Instructional hypermedia environments, for instance, represent such learning offers as they require learners to autonomously structure and control their learning process (Scheiter & Gerjets, 2007). Importantly, hypermedia environments are particularly suited to convey complex knowledge domains and to better benefit high-level or complex thinking than linear environments (CFT; Jacobson & Spiro, 1995; Spiro & Jehng, 1990). Thus, hypermedia environments seem to be an appropriate learning offer for advanced learners with high WM capacities who rather strive for mastering complex learning goals than to simply recall facts. However, it has not yet been investigated whether WM capacity represents a necessary learning prerequisite to benefit more from hypermedia instruction than from linear instruction for complex task demands. Therefore, the second study of the current dissertation addresses the research question as to whether children with high WM capacity benefit more from a hypermedia learning environment than from a linear learning environment for complex task demands (Research Question 2). Specifically, the differential role of WM capacity on the performance of fourth-graders working either through a multiperspective hypermedia environment or a linearly structured learning environment will be explored (further details will be given below).

Concerning the third research question, the present dissertation aims to investigate navigational processes during hypermedia learning. Navigation is a crucial issue of hypermedia environments as it has been demonstrated to strongly impact comprehension and learning in this context (e.g., Lawless et al., 2003; Naumann et al., 2008). Navigational demands included in hypermedia environments concern, for instance, finding and locating relevant information, inhibiting irrelevant information, dividing attention between co-occurring information, or switching between different perspectives (e.g., McDonald & Stevenson, 1996; Niederhauser et al., 2000). These navigational demands require a high degree of executive control from the learner and, thus, high WM resources (e.g., McDonald & Stevenson, 1996). However, it has not yet been empirically investigated whether high WM resources positively influence navigation in hypermedia environments. Therefore, this issue is addressed in the third study of this dissertation. More precisely, Study 3 dwells on the interplay of WM capacity, navigational processes, and hypermedia learning in order to examine whether effective navigational processing mediates the assumed positive relationship between WM capacity and hypermedia learning (Research Question 3). Specifically, fourth-graders' navigational behaviors while exploring a multiperspective hypermedia environment will be assessed via log files and related to their WM capacity as well as to their exploration performance and learning outcomes (further details will be given below).

Altogether, these three studies aim to shed light on the interplay of giftedness, WM capacity, and hypermedia learning. In order to ensure a common thread, some important issues are held identical throughout all studies. First, the sample always consists of fourth-graders attending an elementary school in Baden-Württemberg. As teachers' nominations of gifted students have been reported to be more reliable for elementary school children than for secondary school children (cf. Endepohls-Ulpe & Ruf, 2005), this target group is chosen for Study 1. For the purpose of comparability, the sample of Study 2 (or 3, respectively) also comprises fourth-graders. Second, the focal construct of WM is always assessed in the same manner. Specifically, children's WM capacity is measured with three WM tasks that cover different content domains (i.e., verbal, numerical, and figural). Two of the three WM tasks are adapted from Vock's (2005) working memory battery, namely the spatial span task assessing visuospatial (i.e., figural) WM capacity, and the listening span task assessing verbal WM capacity. The third WM task is a digit version of the n-back task, namely a 2-back task (numerical material). All WM tasks are presented computer-based, which guarantees a standardized assessment of the children's WM capacity. Importantly, whereas the n-back task represents a typical WM measure in the tradition of cognitive neuroscience (e.g., Jaeggi et al., 2010), the other two WM measures represent typical measures in the tradition of cognitive psychology (e.g., Baddeley, 1986). To conclude, the WM measures used in the present dissertation do not only cover all content domains and guarantee a standardized computer-based assessment, but also integrate two different research traditions. Third, Study 2 and Study 3 refer to the same hypermedia learning environment. Specifically, a multiperspective hypermedia environment (cf. Lima et al., 2002) that covers the topic 'biodiversity of fish' and thus implies the idea of multiperspectivity (i.e., a topic that requires from the learner to take multiple viewpoints simultaneously into consideration) is used. The multiperspective hypermedia environment is developed for tablet computers (i.e., iPads) as touch screen interfaces are assumed to be more adapted to the skills of younger children who still perceive difficulties with features of a traditional computer (Lane & Ziviani, 2010). With traditional computers, for example, the mouse interaction is spatially separate from the perceived effects which makes it more difficult to handle, whereas touch screens allow performing actions that directly appear on the screen (e.g., Lu & Frye, 1992; Scaife & Bond, 1991). Moreover, touch screens enable more intuitive manipulations and allow for a more active interaction than traditional computers (Geist, 2011). Finally, Study 3 even refers to a subsample of Study 2, namely to the children who worked through the multiperspective hypermedia environment in Study 2. In the following, the three empirical studies will (now) be described more precisely (see Table 3 for a comprehensive overview).

Study 1 (*What Characterizes Children Nominated as Gifted by Teachers? A Closer Consideration of Working Memory and Intelligence*) focuses on the role of WM in describing teacher-nominated gifted children. As prior research has consistently shown that not all children nominated as gifted by teachers have high intelligence, which is considered to be the most important cognitive variable in the field of giftedness, it is likely to assume that these children exhibit important additional cognitive characteristics. In order to further understand the characteristics of these students, Study 1 explores the role of the so-far-unattended cognitive construct of WM. First, teacher-nominated gifted children are compared to children not identified as gifted with regard to their WM capacity and their STM capacity. STM tasks are included to rule out the possibility that it is the simple storage buffer instead of the executive control functions that discriminates between teacher-nominated gifted children and other children (cf. Swanson, 2006). Specifically, it is assumed that teacher-nominated gifted children have a higher WM capacity but not a higher STM capacity than other children. Second, the discriminative role of WM is compared to the role of fluid intelligence to find out whether WM might be equal to or even more important than intelligence in characterizing teacher-nominated gifted children. To this end, the constructs of WM, STM, as well as fluid intelligence were assessed in a sample of N = 81 fourth-graders. WM was assessed with the three WM measures described above. Likewise, three STM measures covering all content domains (verbal, numerical, and figural) were applied to gauge the children's STM capacity (i.e., word list recall, digit list recall, visual pattern recall; see Hasselhorn et al., 2012). Finally, fluid intelligence was measured with the short version of the Culture Fair Test 20-R (CFT 20-R; Weiß, 2008). Importantly, 42 of the children had been identified as gifted by their teachers (teacher-nominated gifted children) and attended an additional enrichment program for gifted children named *Hector Children Academies,* a statewide enrichment program to promote the 10% most gifted elementary school children. The other 39 children (control group children) were recruited from one elementary school and had not been nominated to attend the program of the Hector Children Academies.

Study 2 (*Hypermedia Exploration Stimulates Multiperspective Reasoning in Elementary School Children With High Working Memory Capacity: A Tablet Computer Study*) focuses on the role of WM capacity for achieving complex learning goals in a multiperspective hypermedia environment. More precisely, multiperspective hypermedia environments have been claimed to be more beneficial than linear environments for complex learning goals but not for simple learning goals (Jacobson & Spiro, 1995; Salmerón & García, 2012). However, multiperspective hypermedia environments are concurrently assumed to impose high cognitive demands onto learners so that not all learners might be able to benefit from them for complex learning goals (e.g., Niederhauser et al., 2000). In this vein, Study 2 explores whether the cognitive construct of WM represents a crucial learning prerequisite for achieving complex learning goals in a multiperspective hypermedia environment as compared with a linear learning environment. Specifically, it is assumed that only children high in WM capacity benefit more from a multiperspective hypermedia environment than from a linear environment with regard to complex learning goals (i.e., complex exploration tasks and multiperspective reasoning) but not with regard to simple learning goals (i.e., simple exploration tasks). For that purpose, as described above, a multiperspective hypermedia environment was developed that, on the one hand, demanded high WM resources but, on the other hand, was also aimed at better supporting the acquisition of complex goals, such as multiperspective reasoning (than a linear environment). Likewise, a linearly structured version of the learning material was implemented as a linear learning environment, which comprised all of the relevant materials that the multiperspective hypermedia environment also contained. 186 fourth-graders from four different elementary schools in Baden-Württemberg either worked with the multiperspective hypermedia environment (N = 97) or with the linear environment (N = 89). The children's answers to 11 simple exploration tasks (i.e., extracting information from one node/perspective in the environment) and six complex exploration tasks (i.e., integrating information from different nodes/perspectives in the environment) served as an indicator of their exploration performance. Moreover, their answers to three scientific problems, which challenged the children to consider a novel topic from multiple perspectives and to subsequently draw elaborated inferences, served as an indicator for their multiperspective reasoning performance (multiperspective reasoning task). Lastly, the children's performance in the three WM measures described above served as an indicator of their WM capacity.

Study 3 (*How Children Navigate a Multiperspective Hypermedia Environment: The Role of Working Memory Capacity*) focuses on the relation between WM capacity, navigational behaviors, as well as exploration performance and learning outcomes when dealing with a multiperspective hypermedia environment. Previous research revealed navigational behaviors such as focusing on task-relevant pages to be most effective in the context of hypermedia learning (e.g., Lawless & Brown, 1997; Richter et al., 2005). Nevertheless, with regard to multiperspective hypermedia environments, which emphasize the multiperspectivity of a knowledge domain, it might not be sufficient to review task-relevant contents (i.e., content processing: selecting a specific content page, such as text or video, without taking the context into account), as these environments are not designed to convey isolated factual knowledge. Instead, they aim to convey broad conceptual knowledge, which rather demands the selection of conceptual overview pages that display the linking structure of the content nodes within different perspectives (i.e., perspective processing). Thus, in the context of multiperspective hypermedia environments, perspective processing should be arguably more effective than content processing. Furthermore, the processing of task-irrelevant materials (irrelevant processing) should be most ineffective. However, the effectiveness of these navigational behaviors (i.e., perspective processing, content processing, irrelevant processing) in multiperspective hypermedia environments has not been investigated yet. Therefore, Study 3 is the first to address this issue. Specifically, it is assumed that perspective processing would be positively, irrelevant processing would be negatively, and content processing would not be associated with performance. More importantly, Study 3 also explores the so far empirically neglected role of WM capacity for navigational processing in multiperspective hypermedia environments. More precisely, it is herein examined to what extent WM capacity is associated with the beforehand mentioned navigational behaviors when exploring a multiperspective hypermedia environment. Specifically, it is assumed that WM capacity would be positively related to perspective processing, negatively related to irrelevant processing, and not related to content processing. Finally, it is investigated whether the navigational behavior of perspective processing mediates the assumed positive association between WM capacity and performance in multiperspective hypermedia environments. In total, the data of the 97 fourth-graders who dealt with the multiperspective hypermedia environment in Study 2 was analyzed. Specifically, the log files provided by the multiperspective learning environment application served as indicators for the children’s navigational behaviors. Moreover, children’s answers to the exploration tasks (cf. Study 2) served as indicators of their exploration performance. Furthermore, after the exploration of the multiperspective hypermedia environment, children’s learning outcomes were assessed with inferential questions (i.e., combining different facts of the currently acquired fish-knowledge and subsequently drawing conclusions) as well as with scientific transfer questions (i.e., transferring the structural knowledge about fish-biodiversity to another subject area). Comparable to Study 1 and 2, the three WM tasks described above served as indicators of the children’s WM capacity.

In the following three chapters (2-4), these three empirical studies outlined above (i.e., Study 1: *What Characterizes Children Nominated as Gifted by Teachers? A Closer Consideration of Working Memory and Intelligence*; Study 2: *Hypermedia Exploration Stimulates Multiperspective Reasoning in Elementary School Children With High Working Memory Capacity: A Tablet Computer Study*; Study 3: *How Children Navigate a Multiperspective Hypermedia Environment: The Role of Working Memory Capacity*) will be presented in great detail.

Table 3

Overview of the Three Studies Conducted Within the Present Dissertation Including (1) the Study Goal, (2) the Research Questions, and (3) a Description of the Sample and Materials

Study	*(1) Study goal*	*(2) Research questions*	*(3) Sample and materials*
Study 1 (What Characterizes Children Nominated as Gifted by Teachers? A Closer Consideration of Working Memory and Intelligence)	Exploring whether WM capacity represents a crucial characteristic of teacher-nominated gifted children, even beyond intelligence	1) Do teacher-nominated gifted children have a higher WM capacity but not a higher STM capacity than other children? 2) Is WM equal to or even more important than intelligence for characterizing teacher-nominated gifted children?	*Sample*: *N* = 42 teacher-nominated fourth-graders; *N* = 39 non-nominated fourth-graders *Materials*: three WM measures (spatial span, listening span, 2-back), three STM measures (word list recall, digit list recall, visual pattern recall), fluid intelligence measures (CFT 20-R)
Study 2 (Hypermedia Exploration Stimulates Multiperspective Reasoning in Elementary School Children With High Working Memory Capacity: A Tablet Computer Study)	Exploring whether high WM capacity represents a crucial precondition for achieving complex learning goals in a multiperspective hypermedia environment as compared with a linear learning environment	1) Does WM capacity moderate children's complex (but not simple) exploration performance in the two learning environments (i.e., multiperspective hypermedia environment and linear learning environment)? 2) Does WM capacity moderate children's multiperspective reasoning performance after they have dealt with one of the two learning environments?	*Sample*: *N* = 186 fourth-graders (*N* = 97 in the multiperspective hypermedia condition; *N* = 89 in the linear learning condition) *Materials*: two learning environments (i.e., multiperspective hypermedia environment and linear learning environment), simple and complex exploration tasks, a multiperspective reasoning task, three WM measures (see Study 1)
Study 3 (How Children Navigate a Multiperspective Hypermedia Environment: The Role of Working Memory Capacity)	Exploring the interplay of WM capacity, navigational behaviors, and performance in the context of a multiperspective hypermedia environment	1) Which navigational behaviors are effective when exploring multiperspective hypermedia environments? 2) How is WM capacity related to respective navigational behaviors? 3) Does the navigational behavior of perspective processing mediate the relation between WM capacity and performance in multiperspective hypermedia environments?	*Sample*: *N* = 97 fourth-graders (who dealt with the multiperspective hypermedia environment in Study 2) *Materials*: multiperspective hypermedia environment, log files, exploration tasks, inferential questions, scientific transfer questions, three WM measures (see Study 1)

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2

What Characterizes Children Nominated as Gifted by Teachers? A Closer Consideration of Working Memory and Intelligence

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Abstract

Teacher nominations are often used in school settings to identify gifted children. However, although high intelligence is part of almost all definitions of giftedness, prior research has consistently shown that not all children nominated as gifted by teachers have high intelligence. In order to further understand the characteristics of these students, we herein explore the role of another cognitive construct, namely working memory (WM). In a sample comprising N = 81 fourth-graders, both WM and intelligence showed the same predictive value for characterizing teacher-nominated gifted children, pointing to the importance of the thus-far-unattended WM for characterizing these students.

Keywords: giftedness; gifted nomination; working memory; intelligence; elementary school

What Characterizes Children Nominated as Gifted by Teachers? A Closer Consideration of Working Memory and Intelligence

The concept of giftedness and the identification of gifted children are critical issues for both giftedness research and practice (Dai, Swanson, & Cheng, 2011; VanTassel-Baska, 2006). Among the various conceptions of giftedness, high intelligence, and more specifically, fluid intelligence, reflects the most generally accepted component of giftedness (Sternberg, Jarvin, & Grigorenko, 2011). Consequently, it is not surprising that intelligence testing is one commonly applied method for identifying gifted children (e.g., Horn, 2007). Alternatively, as the selection of gifted students is often guided more by practical than by conceptual reasons (Friedman-Nimz, 2009), another frequently used method for identifying gifted children is teacher nominations (e.g., Freeman & Josepsson, 2002; Threlfall & Hargreaves, 2008). Although teachers themselves indicate that they consider high intelligence an important characteristic for giftedness (Endepohls-Ulpe & Ruf, 2005), research has frequently shown that not all students nominated as gifted by teachers fulfill the high-intelligence criterion (e.g., Gear, 1978; Neber, 2004). Accordingly, children nominated as gifted by teachers might exhibit important characteristics besides intelligence.

In line with the common view that giftedness is mainly constituted by cognitive performances (cf. Freeman, 2005; Jeltova & Grigorenko, 2005), we herein focus on another cognitive construct that might affect whether a child is nominated as gifted by teachers or not, namely working memory (e.g., Baddeley, 2007; Oberauer, 2009). Whereas, on the one hand, working memory (WM) shows a large amount of overlap with intelligence (Kyllonen & Christal, 1990), on the other hand, it can clearly be discriminated from intelligence. Specifically, WM captures low-level cognitive processes (e.g., storing, manipulating) as opposed to higher-level cognitive functioning (e.g., logical reasoning, induction).

WM has been found to be as predictive as intelligence of a variety of cognitive performances linked to learning and educational development (e.g., Alloway & Alloway, 2010; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Toll, Van der Ven, Kroesbergen, & Van Luit, 2011). For instance, WM has been shown to affect mathematical problem solving (Swanson, 2011), reading comprehension (Seigneuric & Ehrlich, 2005), and language learning (Leonard et al., 2007). For younger children, WM is even reported to be a better predictor of learning than intelligence (Alloway & Alloway, 2010; Hoard, 2005). Overall, WM is considered an important cognitive characteristic, besides intelligence, for learning and education. However, to the best of our knowledge, WM has not yet played an important role in research that has examined the characteristics of teacher-nominated gifted children. Thus, we intended to extend previous literature by focusing on a potentially new, important cognitive variable, namely WM capacity, for characterizing teacher-nominated gifted children.

Working Memory

Working memory can be described as a system for temporarily storing and manipulating information during cognitive activity (Baddeley, 2002). Whereas most researchers agree that WM consists of multiple interacting subsystems, there are important differences in how the structure of these subsystems has been conceptualized (e.g., Baddeley & Hitch, 1974; Engle, Kane, & Tuholski, 1999; Logie, 2011; Oberauer, Süß, Schulze, Wilhelm, & Wittmann, 2000). According to the seminal work by Baddeley and Hitch (1974), WM consists of three components: the central executive, the phonological loop, and the visuospatial sketchpad. Whereas the central executive is defined as an attentional control system, the two other components are considered to be slave systems responsible for keeping the to-be-processed information active in memory. Specifically, spatial or visual information is stored in the visuospatial sketchpad, and verbal information is stored in the phonological loop. The idea of two different slave systems has also been supported by other WM models (e.g., Oberauer et al., 2000). However, the existence of an independent unitary central control structure (i.e., central executive) has been criticized. Instead, current research suggests a range of executive functions underlying the control and regulation of information in WM, such as focusing and sustaining attention, task switching, updating, and inhibition (Baddeley, 2007; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Oberauer, 2009).

Irrespective of the controversy about the structure of WM, there is rather common agreement about its specific functions. Specifically, WM is considered to incorporate two main functions: active storage and executive control (e.g., Yuan, Steedle, Shavelson, Alonzo, & Oppezzo, 2006). On the basis of these functions, a clear distinction between WM and the more traditional concept of short-term memory (STM) can be derived. Whereas STM can be described as a simple storage buffer whose capacity is determined merely by storage requirements, the functionality of WM is more complex, as it jointly has to fulfill storage and executive control requirements. Thus, STM is conceptually different and can be considered to be only a subset of WM (Engle, Tuholski, Laughlin, & Conway, 1999; Unsworth & Engle, 2007). To assess STM capacity, *simple span tasks* that require merely the storing of information are typically used. To assess WM capacity, complex measures that involve the simultaneous storage and executive processing of information are used. Two of the most frequently applied types of WM tasks are *complex span tasks*, which are typically used in cognitive psychology research (e.g., Baddeley, 2002), and the *n-back task*, which is a standard working memory measure in neuropsychological research (e.g., Jaeggi, Buschkuehl, Perrig, & Meier, 2010).

Working Memory and Intelligence

Some studies have indicated strong correlations between WM and intelligence, particularly with fluid intelligence, both for adults (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Kyllonen & Christal, 1990) and for children (Fry & Hale, 2000; de Jong & Das-Smaal, 1995; Vock, 2005). According to the meta-analysis by Ackerman, Beier, and Boyle (2005), the average correlation between WM and fluid intelligence is r = .48. However, it is still unclear what drives this relation. Whereas some have argued that the STM component of WM might be responsible for the correlation with intelligence (Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008), there is also literature demonstrating that the strong link between WM and intelligence is not at all influenced by STM (Conway et al., 2002). The meta-analysis by Ackerman et al. (2005) reports an average correlation between STM and fluid intelligence of r = .26, indicating that STM is neither unimportant nor very important for the relation between WM and intelligence.

Besides the empirical support that WM and fluid intelligence moderately overlap, the constructs are considered to reflect different capabilities from a theoretical point of view. Specifically, WM is seen to represent a system for the maintenance and executive processing of information over a short time period, while simultaneously operating cognitively (Baddeley, 2002). Fluid intelligence, by contrast, is regarded as a complex cognitive ability that helps a person to cope mentally with new situations and problems, and can also be understood as inductive thinking (Cattell, 1961). Accordingly, fluid intelligence can be described as higher-level cognitive functioning, as it refers to relatively complex cognitive processes such as logical reasoning, making analogies, or problem solving, while WM is a lower-level cognitive structure requiring only simple cognitive operations such as storing, updating, or focusing attention (Matzke, Dolan, & Molenaar, 2010; Miyake et al., 2000; Süß, Oberauer, Wittmann, Wilhelm, & Schulze, 2002). For this reason, at first glance, one might suggest that fluid intelligence would be a better characteristic for describing teacher-nominated gifted children. However, studies that have revealed that not all students nominated as gifted by their teachers have extraordinary high intelligence (e.g., Neber, 2004) suggest that, in addition to intelligence, other characteristics may also influence teachers' perceptions of giftedness. In light of the commonly accepted importance of cognitive capabilities for giftedness (Subotnik, Olszewski-Kubilius, & Worrell, 2011), and due to the fact that WM shows high predictive power for various cognitive competencies (Swanson, 2011), in some instances even stronger than intelligence (e.g., Alloway & Alloway, 2010), it seems conceivable that this construct also characterizes teacher-nominated gifted children, even in addition to intelligence.

Previous Research Linking Working Memory to Gifted Children

There have already been some attempts to understand the role of WM in describing gifted children, but nearly all of these studies have focused on gifted children identified by cognitive achievement tests such as the SAT or intelligence tests (Hoard, 2005; Hoard, Geary, Byrd-Craven, & Nugent, 2008; Swanson, 2006; Vock, 2005). Stated briefly, the results of these studies indicated that gifted children had a higher WM capacity than non-gifted children. However, it is still unclear whether these differences concern functions that are only specific to WM or also include simple STM functions.

Neither the role of WM nor of STM in characterizing teacher-nominated gifted children has been adequately investigated yet. In fact, to the best of our knowledge, there is only one study that investigated the WM and STM capacities of teacher-nominated gifted children (Okamoto, Curtis, Jabagchourian, & Weckbacher, 2006). Although this study found no support for the idea that the tested sample of teacher-nominated gifted students had a WM or STM capacity higher than the norm, it has to be noted that the study did not allow a valid conclusion to be made because it lacked a non-gifted control group and used only one unstandardized measure of WM and STM.

The Present Study

The present study aimed to investigate the role of WM in describing teacher-nominated gifted children. Based on findings that have indicated that WM has the power to predict different cognitive performances (e.g., Alloway & Alloway, 2010; Swanson, 2011), we assumed that WM would be a crucial characteristic of these children. Specifically, we expected that these children would have a higher WM capacity than other students (Hypothesis 1a).

We additionally included STM tasks to explore whether it is the simple storage buffer instead of the executive control functions that discriminates between teacher-nominated gifted children and other children (cf. Colomn et al., 2008). However, as STM has less often been found to influence learning and cognitive performances (e.g., Daneman & Merikle, 1996), we assumed that STM would not differentiate between teacher-nominated gifted children and those not nominated (Hypothesis 1b).

Finally, from an exploratory point of view, we wanted to compare the discriminative role of WM to the role of fluid intelligence. Based on previous findings that not all students nominated as gifted by teachers fulfill the high-intelligence criterion (e.g., Neber, 2004), and that the power to predict cognitive performances is sometimes even stronger for WM than for intelligence (e.g., Alloway & Alloway, 2010), we wanted to find out whether WM might be equal to or even more important than intelligence in characterizing teacher-nominated gifted children.

Method

Participants

Eighty-one fourth graders (48.1% female) from Baden-Württemberg, Germany, participated in the study. The children's age ranged from 8 to 12 (M = 9.7, SD = 0.63) years. Forty-two of the children had been nominated as gifted by their teachers (teacher-nominated gifted group) and attended an additional enrichment program for gifted children named Hector children academies, a statewide enrichment program. This program is designed to provide enrichment for the top 10% of gifted elementary school students in the state of Baden-Württemberg. To this end, teachers are asked to nominate up to the 10%, in their view, most gifted students of their class prior to the start of the course. Experiences with the Hector children academies show that typically all children who are nominated actually attend the enrichment program. This procedure of teacher-based gifted nomination has also been applied by many other studies (e.g., Freeman & Josepsson, 2002; Threlfall & Hargreaves, 2008). The nominated children are then allowed to attend the enrichment program of the Hector children academies which usually takes place in the afternoon at one of approximately 60 elementary schools that have been successfully applied for being a Hector children academy. All children from the teacher-nominated gifted group were recruited from one Hector children academy, and the 39 other children (control group) were recruited from the same elementary school but did not attend the academy. As all children originated from the same region, it is likely that both groups were generally comparable with regard to specific background characteristics. For all children, parental approval for participation was obtained. The children attending the Hector children academy did not differ significantly from the control group children in terms of gender ($\chi^2(1, 81) = .11$; $p = .74$) and age ($t(79) = 1.69$; $p = .10$; for means and standard deviations, see Table 1).

Measures and Procedures

All children completed a fluid intelligence test and three WM tasks, as well as three STM tasks. By using different types of WM and STM measures, we ensured that the tasks covered different content domains (verbal, numerical, figural; cf. Oberauer et al., 2000). The intelligence test was conducted in a group setting and lasted 45 minutes. The computer-based WM and STM tasks were administered to each child individually, between 1 and 10 days after the intelligence test. These six tasks were assigned to each child in random order and lasted about one hour in total.

Intelligence Measure

In order to assess fluid intelligence, we applied the short version (cf. Förster & Souvignier, 2011) of the commonly used Culture Fair Test 20-R (CFT 20-R, Weiß, 2008). More precisely, the short version of the CFT 20-R contains four language-free subtests independent of culturally specific knowledge, namely sequence completion, classification, matrices, and topology. The internal consistency was $\alpha = .73$.

Working memory measures

The three WM tasks involved simultaneous storage and executive control requirements. Two WM tasks (spatial span, listening span) were adapted from Vock's (2005) working memory battery and can be described as complex span tasks. The spatial span task ($\alpha = .74$) was used to measure visuospatial WM capacity. Therein, the children had to memorize black and white patterns shown in a 3 x 3 matrix (storage) and subsequently rotate them mentally, either 90° to the right or to the left (executive control). After a sequence of one to four patterns, the children had to indicate the cells that corresponded to each rotated pattern on a completely white matrix. There were 15 trials ordered from easiest (one pattern) to difficult (four patterns). The listening span task ($\alpha = .66$) was used to assess verbal WM capacity. To this end, children listened to a sequence of simple sentences (e.g. "Humans have a nose." "I see with my ears.") and had to verify each sentence by stating "true" or "false" (executive control). Simultaneously, they had to memorize the last word of each sentence (storage). After a series of three to six sentences, the children had to recall the final word of each sentence in the correct order. There were 11 trials ordered from easiest (three sentences) to difficult (six sentences).

Additionally, we used a digit version of the n-back task (cf. Shallice et al., 2002), specifically a 2-back task (α =.74). The children saw a sequence of single-digits that appeared one at a time at the center of the screen and were instructed to indicate whether the current digit was identical to the digit presented two digits before or not by pressing a key. The task consisted of 24 trials and required the children to remember the last two digits presented (storage) and to continuously update the set of numbers (executive control).

We tested for unidimensionality of the WM tasks using a Principal Components Analysis, which produced a one-factor solution (eigenvalue 1.5) accounting for 50.3% of the total variance. Based on this, we used a composite score in further analyses by building a mean of all (beforehand z-standardized) WM tasks.

Short-term memory measures

The three STM tasks (word list recall, digit list recall, visual pattern recall) involved mere storage requirements and were taken from the AGTB 5-12, a test battery for children (Hasselhorn et al., 2012). The word list recall (α = .81) represented the verbal domain. Herein, children heard a sequence of words and had to recall each sequence in the correct order. The digit list recall (α = .86) represented the numerical domain. Herein, children heard a sequence of digits and had to recall each sequence in the correct order. The visual pattern recall (α = .97) represented the visuospatial domain. Herein, children were shown a 4 x 4 matrix, with two to eight cells colored black, and had to remember the location of these black cells. Each of the three tasks consisted of 10 trials (for further information on these tests, see Hasselhorn et al., 2012).

We also tested for unidimensionality of the STM tasks using a Principal Components Analysis, which produced a two-factor solution (eigenvalue 1.5 and 1.0) accounting together for 84.4% (50.5% and 33.9%) of the total variance. Whereas the word list recall and the digit list recall loaded on the first factor, the visual pattern recall loaded on the second factor. This corresponds to the idea of two different slave systems – the phonological loop and the visuospatial sketchpad (Baddeley & Hitch, 1974; Oberauer et al., 2000). Based on this, we used two composite scores in further analyses; on the one hand, we built a mean of the (z-standardized) word list recall and the (z-standardized) digit list recall ($STM_{verb/num}$), and on the other hand, we left the (z-standardized) visual pattern recall separate (STM_{fig}).

Results

Table 1 presents means and standard deviations for IQ scores for both groups. The mean IQ of the teacher-nominated gifted group was significantly higher than that of the control group ($t(79) = -3.49$, $p = .001$, $d = .77$), though the mean IQ of the teacher-nominated gifted group was within one standard deviation of the IQ-norm, $M = 112.26$ ($SD = 11.68$). Still, this result mirrored other studies in which children were nominated as gifted by teachers (Gear, 1976), also concerning German samples (Neber, 2004; Schulthess-Singeisen, Neuenschwander, & Herzog, 2008). Moreover, this result further substantiated the assumption that teacher-nominated gifted children exhibit other (additional) characteristics beyond intelligence.

Table 1

Mean Scores (Standard Deviations) of Age and IQ as well as Percentages of Gender for the Teacher-Nominated Gifted Group and the Control Group.

Measurement	Teacher-nominated gifted group (n = 42)	Control group (n = 39)
Age in years	9.60 (0.67)	9.87 (0.67)
IQ	112.26 (11.68)	101.95 (14.85)
Sex	48% female	49% female

Table 2 presents correlational analyses across intelligence, the WM composite score, the three WM tasks (listening span task, 2-back task, spatial span task), the $STM_{verb/num}$ composite score, the corresponding STM tasks (word recall task, digit recall task), and the STM_{fig} score (visual pattern task). Note that correlations among the individual tasks are influenced by stimulus material supporting again the assumption of different slave systems (Baddeley & Hitch, 1974).

Table 2

Intercorrelations Between Intelligence, WM (Composite Score), the Listening Span Task, the 2-Back Task, the Spatial Span Task, $STM_{verb/num}$, the Word Recall Task, the Digit Recall Task, and STM_{fig} (Visual Pattern Task).

	1	2	3	4	5	6	7	8	9
1. **Intelligence**	-								
2. **WM**	.42**	-							
3. Listening span	.21	.65**	-						
4. 2-back	.21	.73**	.16	-					
5. Spatial span	.46**	.74**	.20	.38**	-				
6. **$STM_{verb/num}$**	.13	.32**	.48**	.12	.05	-			
7. Word recall	.12	.19	.38**	.05	-.05	.87**	-		
8. Digit recall	.11	.36**	.45**	.17	.14	.87**	.51**	-	
9. **STM_{fig}**	.43**	.38**	.09	.33**	.40**	.02	-.05	.09	-

Note. N = 81; *p < .05, **p < .01.

Working Memory and Short-Term Memory

Concerning Hypotheses 1a and b, which predicted that teacher-nominated gifted children possess a higher WM capacity but not a higher STM capacity than other children, we compared the two groups in their WM capacity and their STM capacity, the latter divided into a $STM_{verb/num}$ score and a STM_{fig} score. As there is reasonable evidence concerning the correlatedness of WM and STM (Colom et al., 2008; Conway et al., 2002), we controlled for STM capacity when comparing the groups in their WM capacity[2]. Descriptive statistics and effect sizes of the different WM and STM measures, as well as the composite scores for the teacher-nominated gifted group and the control group, are shown in Table 3 (note that our WM tasks did not provide norm-referenced scores so that the absolute values of the students could not be classified).

[2] Note that we also controlled for gender (n.s.) and age (n.s.) to take more potentially influential variables into account. However, for reasons of clarity and as both variables did not appear to be significant, we did not report their statistics in detail.

Table 3

Descriptive Statistics - Mean Scores (Standard Deviations) – and Effect Sizes of the Three WM Tasks, the Three STM Tasks and the Composite Scores (WM, $STM_{verb/num}$, STM_{fig}) for the Teacher-Nominated Gifted Group and the Control Group.

Measurement (range)		Teacher-nominated gifted group (n = 42)	Control group (n = 39)	Effect Size (Cohen's *d*)
Working memory measures	Spatial span (1-15)	9.02 (2.29)	7.87 (2.77)	0.45
	Listening span (1-11)	8.97 (0.61)	8.52 (0.63)	0.73
	2-back (percentage correct)	73.76 (10.94)	64.72 (19.29)	0.58
	WM composite score (z-standardized)	0.27 (0.57)	-0.28 (0.74)	0.84
Short-term memory measures	Visual pattern recall (STM_{fig}) (1-10)	5.31 (1.45)	5.37 (1.53)	0.04
	Word list recall (1-10)	3.32 (0.48)	3.19 (0.48)	0.27
	Digit list recall (1-10)	5.18 (0.68)	4.99 (0.56)	0.31
	$STM_{verb/num}$ composite score (z-standardized)	0.14 (0.86)	-0.15 (0.86)	0.33

A univariate ANCOVA revealed that the teacher-nominated gifted group had a significantly higher WM capacity than the control group (F (1, 74) = 14.71, p < .001, d = .84). As we controlled for STM capacity when comparing the children in their WM capacity, we can rule out the possibility that STM capacity accounts for the difference in WM capacity. By contrast, the teacher-nominated gifted group did neither differ significantly from the control group in their $STM_{verb/num}$ (F (1, 76) = 1.78, p = .186, d = .33) nor in their STM_{fig} (F (1, 76) = 0.03, p = .865, d = .04). These results thus confirmed Hypotheses 1a and b.

Importance of Working Memory and Intelligence for Giftedness

To examine whether WM is equal to or even more important than intelligence in characterizing teacher-nominated gifted children, we conducted three logistic regression analyses. In Model 1, we tested the unique power of intelligence, in Model 2 the unique power of WM, and in Model 3 the shared power of IQ and WM for correctly predicting whether a child had been nominated as gifted or not (dependent variable: nominated as gifted). Additionally, we looked at changes in the percentages of children correctly classified in the teacher-nominated gifted group or control group by these models. For the purpose of controlling the correlatedness between WM and STM, we included $STM_{verb/num}$ and STM_{fig} as covariates in Models 2 and 3[3]. Beforehand, all predictor variables (i.e., IQ, WM, $STM_{verb/num}$, and STM_{fig}) were z-standardized for reasons of effect size interpretation. As we z-standardized across the whole sample, correlations between the predictors - including the statistical control of differences among the groups - were unaffected. The results of these analyses are shown in Table 4.

Model 1 revealed that IQ was a significant predictor of being nominated as gifted. We used *Nagelkerkes* R^2 as a coefficient of determination for the model. Note that although *Nagelkerkes* R^2 is typically used when performing logistic regression analyses, it is not equivalent to the R^2 used in OLS regression. In Model 1, IQ explained R^2 = .21 of the variance. Moreover, IQ significantly improved the model fit with a log likelihood difference of 13.40 (df = 3, p = .004) compared to the intercept model. In addition, the overall percentage of correct classifications based on IQ was 65.0%.

In Model 2, WM also revealed to be a significant predictor of being nominated as gifted. STM, by contrast, did not predict gifted nomination. WM (and STM) explained R^2 = .30 of the variance and improved the model fit with a log likelihood difference of 20.71 (df = 5, p = .001) compared to the intercept model. In addition, the overall percentage of correct classifications based on WM (and STM) was 68.8%.

[3] Note that we also included gender (n.s.) and (z-standardized) age (n.s.) as control variables in the logistic regression analyses (see also Footnote 1).

Table 4

Summary of the Hierarchical Logistic Regression Analyses Testing the Contributions of Intelligence (IQ) and Working Memory (WM) – While Controlling for Short-Term Memory ($STM_{verb/num}$, STM_{fig}) – to the Prediction of Being Nominated as Gifted (Teacher-Nominated Gifted Children: n = 42 vs. Control Group Children: n = 39).

	Predictor	***b***	***SE***	***Wald's χ^2***	***df***	***p***	***Odds ratio***
Model 1	Constant	0.21	0.34	0.36	1	.564	1.23
	IQ	0.81	0.28	8.48	1	.004	2.24
Model 2	Constant	0.22	0.36	0.36	1	.547	1.24
	$STM_{verb/num}$	0.04	0.27	0.18	1	.893	1.04
	STM_{fig}	-0.51	0.29	3.03	1	.082	0.60
	WM	1.29	0.39	11.01	1	.001	3.63
Model 3	Constant	0.33	0.38	0.73	1	.391	1.39
	$STM_{verb/num}$	0.08	0.30	0.67	1	.795	1.08
	STM_{fig}	-0.88	0.35	6.24	1	.012	0.41
	IQ	0.94	0.36	6.80	1	.009	2.56
	WM	1.10	0.39	7.91	1	.005	3.00
	Test	***χ^2***	***df***	***p***	***χ^2_{diff}***	***Nagelkerkes R^2***	***% correct classification rate***
Model 1	IQ	97.31	3	.004	13.40	.21	65.0
	Goodness of Fit test (H-L)	10.43	8	.236			
Model 2	WM + STM	89.99	5	.001	20.71	.30	68.8
	Goodness of Fit test (H-L)	5.05	8	.752			
Model 3	IQ + WM + STM	83.32	6	< .001	28.38	.40	75.0
	Goodness of Fit test (H-L)	7.92	8	.441			

Finally, IQ, WM, $STM_{verb/num}$, and STM_{fig} were simultaneously entered into Model 3. Model 3 reduced the log likelihood ratio of the intercept model by 28.38 (df = 6, p < .001) and reached a correct classification rate of 75.0%. The explained variance increased to R^2 = .40. Thus, being nominated as gifted by teachers was best predicted by both WM and IQ taken together (Model 3). Within Model 3, both WM and IQ were significant predictors, meaning that both variables possessed unique validity. The confidence intervals of WM (OR = 3.00, 95% CI = 1.39-6.43) and IQ (OR = 2.56, 95% CI = 1.26–5.17) implied that their predictive values for giftedness nomination were on a similar level. Nonetheless, WM had a descriptively higher b-coefficient and odds ratio compared to IQ, suggesting that WM was at least as important as IQ for characterizing teacher-nominated gifted children. Moreover, whereas $STM_{verb/num}$ did not significantly predict giftedness nomination, STM_{fig} revealed to be a significant predictor. However, the b-coefficient of STM_{fig} turned out to be negative, indicating that teacher-nominated gifted children did not exhibit high levels in STM_{fig} at all.

Discussion

The present study investigated the role of WM in characterizing teacher-nominated gifted children. More precisely, we assumed that WM would be a crucial characteristic of these children and wanted to find out whether it could discriminate equally to or even better than intelligence between teacher-nominated gifted children and those not nominated. The results of this study indicated that WM capacity was significantly higher for teacher-nominated gifted children as compared to other children. STM, by contrast, did not differentiate the group of teacher-nominated gifted children from the control group suggesting that the executive control functions of WM, rather than the storage functions, were crucial for characterizing teacher-nominated gifted children. These findings are in line with previous studies that have shown that gifted children identified by cognitive achievement tests had a higher WM but not a higher STM capacity compared to other students (Swanson, 2006; Vock, 2005). Consequently, this result indicates that STM does not account for the relation between WM and nominations of gifted children by teachers – although it might account for the relation between WM and intelligence (e.g., Colom et al., 2008). Moreover, in our study, WM and IQ together best discriminated between teacher-nominated gifted children and those not nominated, with each construct contributing significantly to the prediction of being nominated as gifted or not. Thus, it seems important to consider both WM and IQ as crucial characteristics of these children. Moreover, both STM components did not disperse the effect of WM on giftedness nomination. Unexpectedly, STM_{fig} revealed to be negatively related to giftedness nomination, indicating that teacher-nominated gifted children exhibited rather low levels in STM_{fig}.

Altogether, these findings might help to further our understanding of teachers' giftedness judgments, which might be affected by students' WM capacity (among other characteristics). However, it still seems unclear whether teachers actually perceive an elementary cognitive process such as WM. Instead, it is also reasonable that teachers perceive other characteristics that are more visible and concurrently strongly associated with WM, for instance, verbal abilities such as reading comprehension (Leong, Hau, Tse, & Loh, 2007; Seigneuric & Ehrlich, 2005), language processing (Shah & Miyake, 1996), or mathematical skills (Alloway & Passolunghi, 2011; Simmons, Willis, & Adams, 2012). Moreover, according to Baddeley (1996), high WM capacity is associated with the conduction of goal-directed behavior, the focus on relevant information or the ability to simultaneously process information. The mentioned characteristics particularly become meaningful in the educational context, and might thus influence teacher's perception of a child's giftedness. Consequently, future studies should delve more deeply into the intertwining between WM and more observable characteristics in the context of giftedness nomination. Nevertheless, the present findings indicate that simple cognitive operations attributed to WM and complex cognitive processes attributed to intelligence provide equal predictive power for giftedness nominations by teachers.

According to Miyake and colleagues (2000), such simple cognitive operations can be differentiated into switching, updating, and inhibition processes. It has been demonstrated that only the updating process, but not the other two processes, are related to intelligence (Friedman et al., 2006). The updating process is mainly involved during working memory demands as information has to be permanently updated in the presence of interference. In line with this, it is likely to argue that it is amongst others, specifically the simple cognitive process of updating that can be treated as equal to the complex cognitive processes of intelligence to predict giftedness nomination.

Limitations and Outlook

Besides the support for considering WM as an important characteristic for (teacher-nominated) gifted students, some limitations of our study should also be addressed. First, as our study used a correlational design, we cannot draw any causal inferences from these data concerning the relation between students' characteristics, such as WM, and teachers' giftedness judgments. Consequently, in a longitudinal design it should be investigated whether teachers' giftedness nominations are indeed affected by children's WM. Second, although we controlled for sex and age, other variables such as school achievement or socioeconomic status (Passow & Frasier, 1996; Rost & Hanses, 1997) might also differentiate between teacher-nominated gifted students and other students. Probably, some of these variables are correlated with WM and thus may have (partly) caused the relation between WM and whether or not a child had been nominated. Third, concerning the generalization of our findings, our sample size was quite small, which is unfortunately relatively common for empirical high ability research (e.g., Bergen, 2009; Cho & Ahn, 2003; Navarro et al., 2006). Moreover, we only investigated children from one elementary school and one corresponding Hector children academy; this might also affect the generalization of our findings. Finally, it is possible that the children of the control group differed from the teacher-nominated gifted children in other potentially relevant variables that we did not measure in the present study. Thus, future research might aim to replicate and extend our study with larger and more representative samples of teacher-nominated gifted children while controlling for more variables so that a more balanced comparison between teacher-nominated gifted children and those not nominated is possible. Additionally, as our WM tasks did not provide norm-referenced scores, replication studies should use test-normed WM measures.

Conclusion

In sum, the present study points to the importance of working memory for characterizing teacher-nominated gifted children. Considering similar findings with gifted children identified via cognitive achievement tests, one might argue that a higher WM capacity is a crucial characteristic of giftedness, and, thus, researchers should consider this capability in giftedness conceptions. Furthermore, from an educational perspective, future research might aim to develop learning environments that stimulate active learning and concurrently require a high level of WM or executive control, respectively, in order to provide support for the optimal learning performance of gifted students (cf. Subotnik, Olszewski-Kubilius, & Worrell, 2012). Certainly, our investigation concludes that WM should be considered more strongly in the field of giftedness.

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3

Hypermedia Exploration Stimulates Multiperspective Reasoning in Elementary School Children With High Working Memory Capacity: A Tablet Computer Study

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Abstract

The present study examined the effects of a multiperspective hypermedia environment as compared with a linear environment—both presented on tablet computers—on learners' ability to extract and integrate information from different perspectives and to engage in multiperspective reasoning. More specifically, we hypothesized a moderating role of a thus-far empirically unattended but theoretically important learning prerequisite for multiperspective learning settings; namely, working memory (WM) capacity. Results revealed that fourth-graders (*N* = 186) with high WM capacity performed better in a multiperspective hypermedia environment than in a linear environment when dealing with a simple exploration task and a multiperspective reasoning task, whereas there were no differences for fourth-graders with low WM capacity. Furthermore, on a complex exploration task, all students performed better in the linear than in the multiperspective hypermedia environment. Thus, multiperspective hypermedia environments seem to require specific learning prerequisites, namely high WM capacity, as well as specific task demands in order to be effective.

Keywords: working memory, multiperspective hypermedia environment, cognitive flexibility theory, elementary school children, multiperspective reasoning

Hypermedia Exploration Stimulates Multiperspective Reasoning in Elementary School Children With High Working Memory Capacity: A Tablet Computer Study

Nonlinear digital learning environments such as the internet and instructional hypermedia environments are becoming more and more common in school contexts as they enable innovative and interactive learning approaches to be used (e.g., Demetriadis, Papdopoulos, Stamelos, & Fischer, 2008; Purcell, Heaps, Buchanan, & Friedrich, 2013). As compared with more traditional learning materials (e.g., textbooks) that provide information in a linear sequence, instructional hypermedia environments present multimedia materials in a network-like structure, thereby stimulating learners to explore information in a nonlinear fashion (Scheiter & Gerjets, 2007). The interconnection of information units in such a network-like structure is assumed to be better suited for emphasizing the complexity of multifaceted knowledge domains (Spiro, Feltovich, Jacobson, & Coulson, 1992) and for helping learners to develop a flexible understanding of such subject matters by stimulating their consideration of multiple perspectives (Spiro & Jehng, 1990; Zydney, 2010). At the same time, however, multiperspective hypermedia environments are typically quite demanding with regard to cognitive resources (Lang, 1995). As will be argued in the present article, the availability of sufficient working memory (WM) resources (e.g., Baddeley, 2012; Cowan, 2013) might be an important learning prerequisite for ensuring that students will optimally benefit from multiperspective hypermedia environments. To our knowledge, however, this has not been investigated yet. Therefore, we aimed to investigate whether high WM capacity represents a crucial precondition for achieving complex learning goals in a multiperspective hypermedia environment as compared with a linear environment.

Specifically, we investigated this research question in a sample of elementary school children because innovative instructional formats such as hypermedia environments are currently an important issue at all levels of the educational system. Especially given the recent availability of tablet computers, which seem to be more adapted to the skills of younger children than traditional computers (Lane & Ziviani, 2010), an increase in digital instructional environments is noticeable even in elementary schools. We consider it a particular strength of our study that we addressed a target group that is so far relatively unexplored with regard to (multiperspective) hypermedia environments.

Hypermedia Learning

Hypermedia environments are information systems that contain multiple information nodes that are interconnected in a nonlinear network-like structure. Furthermore, the information is displayed in different representational formats such as text, pictures, or videos (Scheiter & Gerjets, 2007). Due to the nonlinearity of the learning materials, hypermedia environments are characterized by high levels of interactivity and learner control. This allows a learner to autonomously decide which information to access in which order and in which kind of representational format. Thus, compared with system-controlled or linearly presented learning materials in which learners are rather passive recipients of a given instructional sequence, hypermedia environments provide an innovative approach for interacting with information. However, research has shown that the rather complex presentation of information in hypermedia environments is not unconditionally beneficial for the exploration performances or learning outcomes of adults or children (Barab, Young, & Wang, 1999; Eveland, Cortese, Park, & Dunwoody, 2004; Hartley, 2001; Lee & Tedder, 2003; McDonald & Stevenson, 1996; Niederhauser, Reynolds, Salmen, & Skolmoski, 2000; Schwartz, Andersen, Hong, Howard, & McGee, 2004). With regard to exploration performance, for instance, hypermedia environments have not been shown to be more suitable than traditional linear materials when a learner is required to merely extract information contained in a single information node (e.g., Cockerton & Shimell, 1997; Salmerón & García, 2012). With regard to learning outcomes, hypermedia instruction has even been demonstrated to be inferior to linear instruction when factual recall is required (Barab et al., 1999; Eveland et al., 2004; Rehbein, Hinostroza, Ripoll, & Alister, 2002; Schwartz et al., 2004). By contrast, hypermedia environments seem to better stimulate high-level or complex thinking and learning processes than linear environments. Specifically, tasks that ask a person to acquire broad conceptual knowledge within a domain, to take multiple viewpoints into consideration simultaneously, or to transfer acquired knowledge to another domain have been shown to be better supported by instructional hypermedia formats than by linear formats (Eveland, et al., 2004; Jacobson & Spiro, 1995; Rehbein et al., 2002). Salmerón and García (2012), for example, demonstrated that sixth-graders were more encouraged by a hypermedia environment to explore information that had to be related and integrated from different information nodes than when the same information was presented in a linear sequence. A suitable theoretical framework that can be used to analyze the particular beneficial effect of hypermedia instruction for complex high-level thinking and learning is cognitive flexibility theory (CFT; Jacobson & Spiro, 1995; Spiro & Jehng, 1990), which will be outlined in the next section.

Cognitive Flexibility Theory and Multiperspective Hypermedia Environments

CFT is a theoretical framework for the design of computer-based learning environments that support complex learning (Jacobson & Spiro, 1995; Spiro & Jehng, 1990). According to CFT, providing multiple perspectives for the exploration of a domain as well as highlighting multiple interconnections among different domain concepts are important design principles for maintaining the complexity of so-called multifaceted knowledge domains that require learners to take multiple viewpoints into consideration simultaneously (cf. Fitzgerald, Wilson, Semrau, 1997; Zydney, 2010). For instance, Jacobson and Spiro (1995) asked learners to assess the impact of technology on 20th-century society and culture from multiple perspectives. In a study by Zydney (2010), students had to deal with divergent viewpoints on a complex air pollution problem. In both studies, the simultaneous consideration of multiple perspectives on the same issue was assumed to facilitate the derivation of a balanced conclusion.

Hypermedia environments are considered to be appropriate for representing knowledge in a multiperspective way because their network-like organization of information can better reflect the multifaceted nature of such complex domains than a linear organization (Scheiter & Gerjets, 2007). As such hypermedia environments allow a topic to be examined from multiple perspectives by revisiting the same contents in a variety of different contexts (Jacobson & Spiro, 1995), they can also be referred to as multiperspective hypermedia environments (cf. Lima, Koehler, & Spiro, 2002). According to CFT, this “criss-crossing” of a conceptual landscape is assumed to foster deeper levels of comprehension, to help people avoid making inept oversimplifications, and to support the construction of a correct mental representation of complex topics (Jacobson & Spiro, 1995; Spiro & Jehng, 1990). These processes, in turn, are supposed to lead to more flexible cognitive structures that enable multiperspective reasoning; that is, drawing elaborated inferences on the basis of the simultaneous consideration of multiple perspectives (cf. Fitzgerald et al., 1997; Zydney, 2010). As a result, multiperspective hypermedia environments should help learners to transfer acquired knowledge elements to novel problem contexts (Spiro et al., 1992).

However, despite these potential advantages, the high amount of autonomy in multiperspective hypermedia environments imposes a large degree of navigational and representational demands on the learner. These demands, in turn, require a substantial degree of cognitive and metacognitive resources such as focusing attention on relevant information, not being distracted by currently irrelevant hyperlinks, or switching between processes of text comprehension (Scheiter & Gerjets, 2007). In addition, the fragmentation of information into smaller hyperlinked units that can be revisited in different contexts might strongly reduce text coherence (Shapiro & Niederhauser, 2004). A lack of coherence can in turn impede text comprehension processes, at least if learners do not possess sufficient cognitive resources to close coherence gaps by drawing the necessary inferences by themselves (McNamara & Kintsch, 1996; Van Dijk & Kintsch, 1983). As a consequence, the advantages of multiperspective hypermedia environments can easily be overshadowed by their costs. Accordingly, CFT recommends that learners should already possess advanced learning prerequisites that might help counteract these high demands (Spiro & Jehng, 1990).

Learning Prerequisites for Exploring Multiperspective Hypermedia Environments

In the context of CFT, previous research has mainly focused on the role of learning prerequisites such as prior knowledge or epistemic beliefs (Demetriadis et al., 2008; Jacobson, Maouri, Mishra, & Kolar, 1996; Land & Zembal-Saul, 2003; Spiro & Jehng, 1990). Studies have shown that students with sufficient prior knowledge and sophisticated epistemic beliefs benefit the most from multiperspective learning environments (Demetriadis et al., 2008; Lowrey & Kim, 2009; Jacobson et al., 1996). However, a few studies still did not find clear educational benefits from multiperspective hypermedia environments for complex learning goals, especially as compared with linear learning environments, even when controlling for the respective learning prerequisites (e.g., Balcytiene, 1999; Lowrey & Kim, 2009; Niederhauser et al., 2000). We believe that this might be due to other learning prerequisites that so far have been overlooked in this context, although they might be crucial for benefitting from multiperspective hypermedia learning environments. As will be argued in the following, WM capacity is a likely candidate for this role.

Working memory and multiperspective hypermedia environments

WM can be described as a system for temporarily storing and manipulating information during cognitive activity (Baddeley, 2012). It consists of two main functions: the active storage of information and the executive control of information processing. Different slave systems, one for visuo-spatial information and the other for verbal information, are suggested to be responsible for actively storing the to-be-processed information (e.g., Baddeley & Logie, 1999; Oberauer, 2009). At the same time, the executive control, which can be decomposed into a variety of executive functions such as focusing attention, task switching, updating, and inhibition, is responsible for the processing and manipulation of information (Baddeley, 2012; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Oberauer, 2009). Accordingly, to assess WM capacity, measures that simultaneously involve both functions are typically used; namely, the active storage of information and the executive control of information processing (cf. Redick et al., 2012). These measures of WM capacity have been shown to predict a variety of learning outcomes (e.g., Alloway & Alloway, 2010; Swanson, 2011). There is also some empirical evidence that WM capacity is important for hypermedia learning (Lee & Tedder, 2003; Naumann, Richter, Christmann, & Groeben, 2008; Pazzaglia, Toso, & Cacciamani, 2008). Pazzaglia and colleagues (2008), for example, showed that verbal and visuospatial WM were both involved in hypermedia learning in a sample of sixth-graders. A study by Naumann and colleagues (2008) demonstrated that students with higher WM capacity benefitted more from a hypertext strategy training in that they subsequently processed a hypertext environment more successfully than students with lower WM capacity. However, to the best of our knowledge, there has been no systematic empirical investigation of the role of WM capacity in multiperspective hypermedia environments yet. Rather, the concept of WM has only been used on a theoretical level as a factor that might explain the occasional lack of beneficial effects of multiperspective hypermedia environments (Lowrey & Kim, 2009; Niederhauser et al., 2000).

Multiperspective hypermedia environments are more complex than linear environments and thus might more easily result in a cognitive overload for learners (Lowrey & Kim, 2009; Niederhauser et al., 2000). Especially with regard to one key objective of CFT—namely, multiperspective reasoning (cf. Zydney, 2010)—learning in a multiperspective hypermedia environment imposes high demands on learners' WM capacity. More specifically, the challenges that come along with multiperspective reasoning, such as considering and switching between different perspectives, deciding on link selection, resolving coherence gaps, and flexibly restructuring one's knowledge tend to impose a heavy load on WM resources (Diamond, 2013; Scheiter & Gerjets, 2007). In addition, learners are required to process large amounts of information, integrate different kinds of information, and keep the results in mind during subsequent processing steps (cf. Ericsson & Kintsch, 1995). Finally, criss-crossing a conceptual landscape to explore different perspectives imposes unfamiliar navigational demands on learners, and such demands may also create a load on cognitive resources (McDonald & Stevenson, 1996; Niederhauser et al., 2000). According to cognitive load theory (Sweller, 1988), an increased cognitive load on WM resources might prevent these resources from being available for the pursuit of deeper comprehension and learning processes (Niederhauser et al., 2000). Consequently, learners with insufficient WM resources might not be able to manage these processing requirements and thus will not benefit from multiperspective hypermedia environments (cf. Lang, 1995). In the present study, we therefore wanted to explore whether high WM capacity might be a particularly important learning prerequisite for predicting whether learners are able to benefit more from multiperspective hypermedia environments as compared with linear learning environments with regard to achieving complex learning goals (e.g., multiperspective reasoning or information integration from different nodes).

The Present Study

The present study aimed to investigate the role of WM capacity for learning with a multiperspective hypermedia environment in a sample of elementary school children. Specifically, we investigated children's exploration and multiperspective reasoning performance as well as the role of their WM capacity when learning in a multiperspective hypermedia environment in comparison with learning in a coherently structured linear environment. In particular, we addressed the following two sets of research questions and hypotheses:

First, we investigated the extent to which WM capacity would moderate children’s *exploration performance* during learning in two different environments. Previous research has shown that hypermedia environments are particularly superior to linear environments when performing complex exploration tasks such as relating and integrating information from different perspectives but not when performing simple exploration tasks such as merely extracting information from a single node (cf. Salmerón & García, 2012). Correspondingly, we expected the multiperspective hypermedia environment to be more beneficial than the linear environment *for complex exploration tasks* but not for *simple exploration tasks*; however, we expected this to hold only for learners with high WM capacity as multiperspective hypermedia environments impose high cognitive demands (cf. Lowrey & Kim, 2009; Niederhauser et al., 2000). Specifically, we expected children high in WM capacity to show a stronger exploration performance in the multiperspective hypermedia environment than in the linear environment when performing complex exploration tasks but not when performing simple exploration tasks (Hypothesis 1a). By contrast, we did not expect children low in WM capacity to benefit more from the multiperspective hypermedia environment than from the linear environment, either when performing complex exploration tasks or when performing simple exploration tasks as they might generally be overwhelmed by the high cognitive demands of the multiperspective hypermedia environment (Hypothesis 1b).

Second, we investigated the extent to which WM capacity would moderate children's *multiperspective reasoning performance* subsequent to learning with one of the two different environments; that is, children's ability to consider multiple perspectives and to draw elaborated inferences when confronted with a novel complex topic that is similarly structured (cf. Zydney, 2010). On the one hand, we expected multiperspective hypermedia environments to better acquaint learners with multifaceted knowledge structures and thus to better stimulate later multiperspective reasoning than linear environments (Spiro et al., 1992). On the other hand, we also expected multiperspective environments to impose a higher load on WM resources than linear environments (e.g., Niederhauser et al., 2000). Therefore, we hypothesized that only children high in WM capacity would benefit more from the multiperspective hypermedia environment than the linear environment in terms of their later ability to engage in multiperspective reasoning (Hypothesis 2a). By contrast, we expected students low in WM capacity to show a low level of multiperspective reasoning after learning in either of the two environments: In the multiperspective condition, they might not be able to cope with the cognitive demands, and in the linear condition, they would receive no stimulation to engage in multiperspective reasoning (Hypothesis 2b).

Method

Participants

The sample consisted of 195 fourth-graders from four different elementary schools in Baden-Württemberg, Germany. Of those, nine children dropped out between the first and second sessions of the study so that the data from 186 children (42.5% female) were analyzed. The children's ages ranged from 9 to 12 years (M = 10.3, SD = 0.45). Active parental approval for participation was obtained for all children.

Materials

Learning domain and exploration tasks

The learning material used in the present study addressed the topic of "biodiversity," a biological topic that implies the idea of multiperspectivity (Collins-Figueroa, 2012). Biodiversity can be taught, for instance, by presenting the diversity of animal species along a number of important dimensions or perspectives (Lindemann-Matthies, 2005). Thus, it qualifies as an appropriate topic for multiperspective hypermedia environments. For the current study, we designed learning materials that dealt with the biodiversity of fish. To keep the children motivated, this topic was embedded in an aquarium story that invited them to take on the role of a fish keeper. In order to meet the requirements of a fish keeper, the children had to learn information about 24 different fish species, for example, on what they eat or how they swim. For this purpose, the children were challenged to consider the fish from six different conceptual perspectives (e.g., in terms of their eating habits or swimming style). To convey this information, we developed a multiperspective hypermedia environment that made it possible to consider and switch between different perspectives.

To further support the exploration of the different perspectives, we provided the children with two types of exploration tasks (cf. Demetriadis et al., 2008) that were designed to guide them through the learning materials. In order to answer these questions, the children were required either to select one out of six conceptual perspectives to find a specific piece of information (simple exploration tasks; e.g., “What is the living environment of the chub?”) or to integrate different perspectives in order to compare and relate various fish species (complex exploration tasks; “Which features differ between the nase fish and the surgeon fish?”). In the linear learning environment, by contrast, all necessary information was coherently structured so that the information that was relevant for answering the next exploration task was automatically presented.

Multiperspective hypermedia environment and linear learning environment

Taking our young sample into consideration, we developed both learning environments for tablet computers, which are assumed to be more intuitive for this population to handle than traditional computers (cf. Lane & Ziviani, 2010).

Multiperspective hypermedia environment. The first screen in the multiperspective hypermedia environment was a comprehensive overview of all 24 fish species available in the learning environment; the species were ordered alphabetically and represented with pictures (see Figure 1). By clicking on a specific fish picture, the picture could be enlarged for inspection, and there were two buttons that allowed the children to retrieve additional text and video information about the fish. Furthermore, different filter buttons (e.g., fish without scales) could be used to highlight a subgroup of fish species. Finally, at the bottom of the alphabetical overview screen, there were six colored buttons that represented the available conceptual perspectives (i.e., alphabetical overview, size, living environment, eating habits, social behavior, and swimming style) according to which the fish could be explored. Clicking on one of these fish-perspective buttons changed the previously alphabetical order of the fish by reordering them according to the categories that were most relevant from a particular perspective.

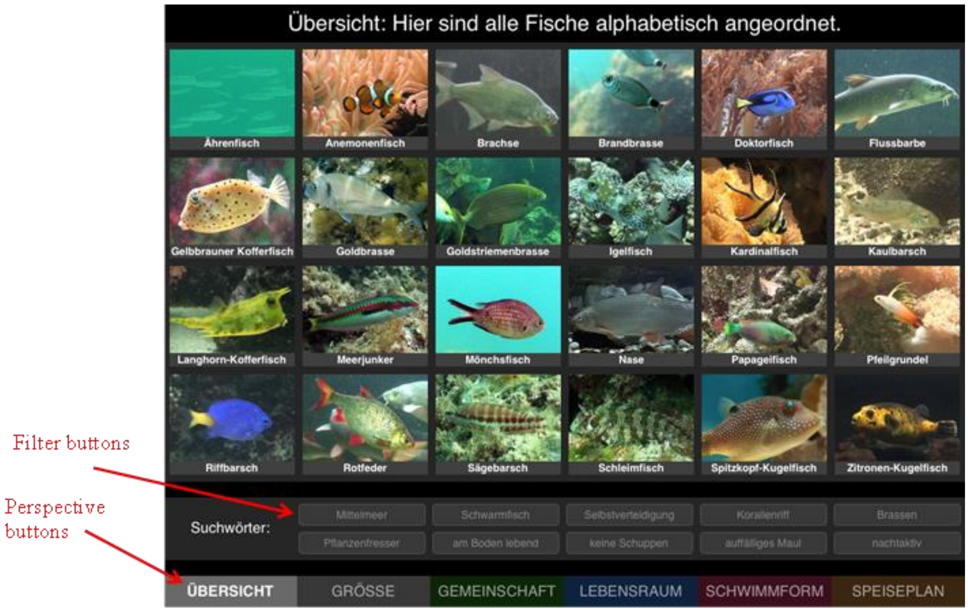

Figure 1. Screen showing the alphabetical overview of the multiperspective hypermedia environment with all 24 fish ordered alphabetically, the filter buttons, and the six perspective buttons.

For instance, by clicking on the "living environment" button, all fish species were sorted into one of the three categories "river," "Mediterranean Sea," or "tropical coral reef" (see Figure 2).

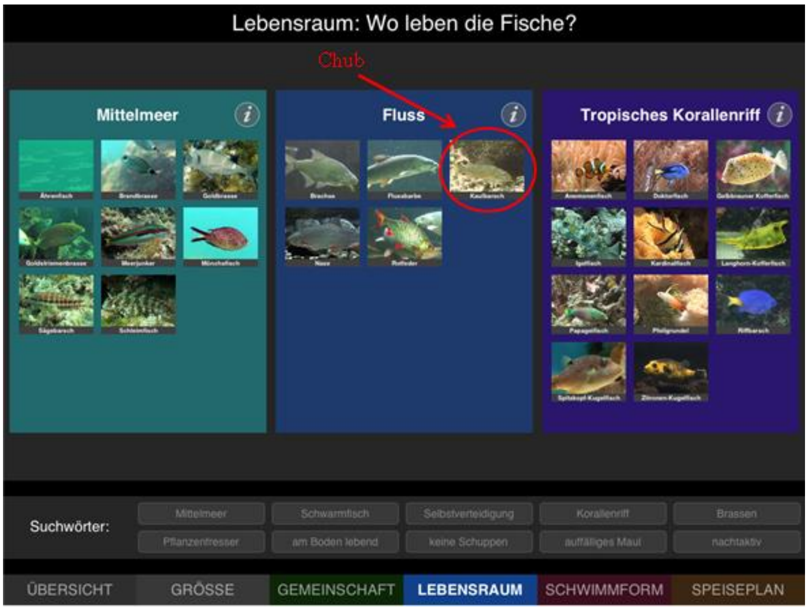

Figure 2. Screen showing the "living environment" perspective from the multiperspective hypermedia environment with all fish sorted into the categories "Mediterranean Sea," "river," and "tropical coral reef" (the chub is circled in red, see simple exploration task).

Detailed information about all categories relevant to a particular conceptual perspective could be obtained by clicking on an information button in the upper right corner of the boxes that were used to represent the categories (see Table 1 for all categories).

Table 1

Overview of All Conceptual Perspectives With Corresponding Categories in the Multiperspective Hypermedia Environment

Perspectives	Categories		
Alphabetical overview	-	-	-
Size	-	-	-
Social behavior	Swarm	Loner	Loose group
Living environment	Mediterranean Sea	River	Tropical reef
Swimming style	*Snaky-swimmer* (sub-carangiform)	*Breaststroker* (labriform)	*Finny-waver* (tetraodontiform)
Eating habits	Plant-eater	Plankton-eater	Shellfish-eater

An exception was the size-perspective in which the fish species were not categorized but rather ordered according to size. Each screen allowed the user to access all fish, the filter buttons, and the different fish-perspective buttons (see Figure 3 for an exemplary extract of the structural associations in the multiperspective hypermedia environment).

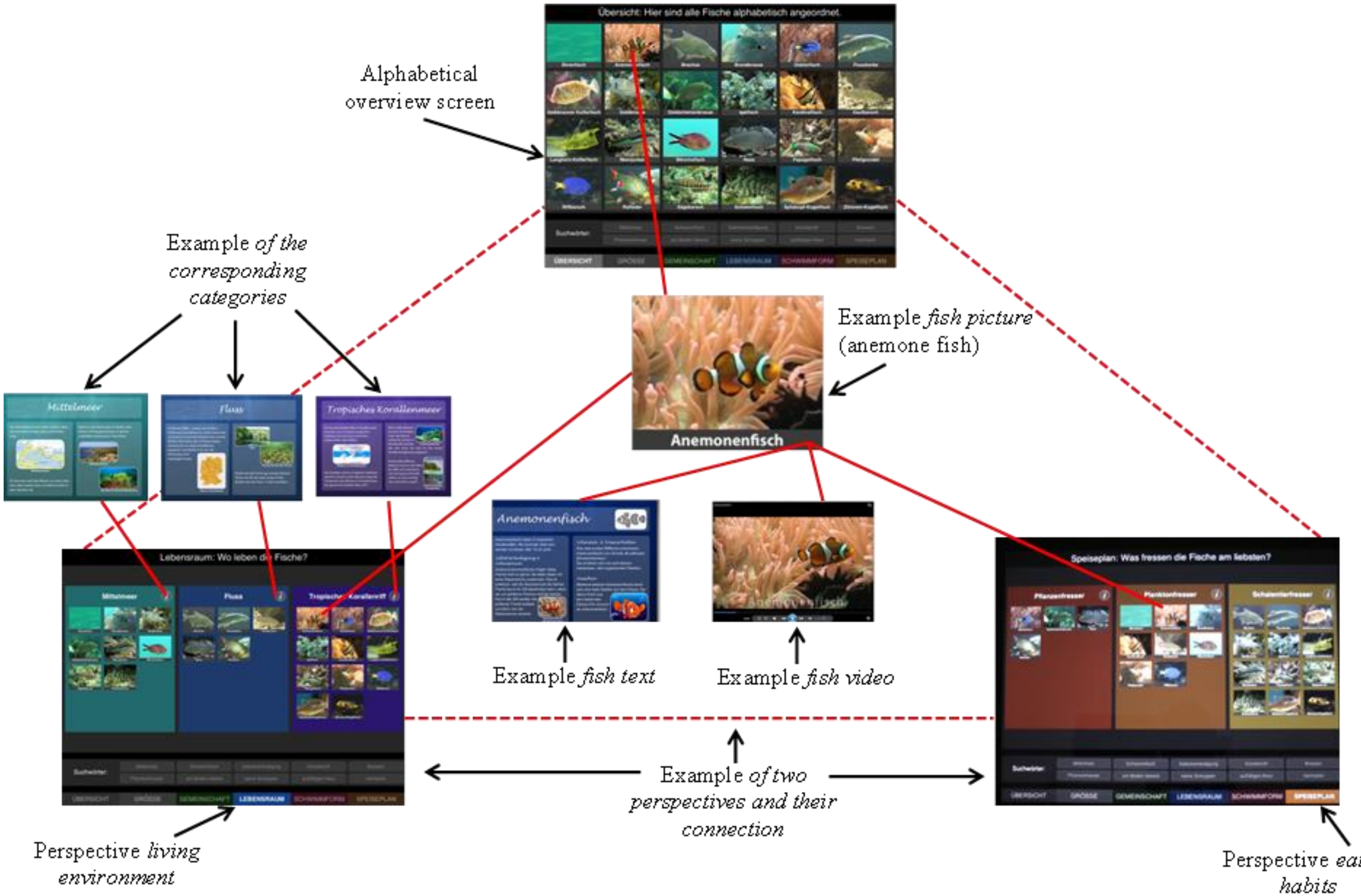

Figure 3. Extract of the structural associations in the multiperspective hypermedia environment: The connections between three exemplary perspectives (alphabetical overview, living environment, eating habits: dashed lines), the corresponding categories of the living environment, and the fish picture, the fish video, and the fish text of the anemone fish are represented in red.

As mentioned above, to guide the exploration of the different conceptual perspectives, we provided the children with exploration tasks (cf. Demetriadis et al., 2008). For example, one simple exploration task asked the children to figure out the living environment of the chub. To this end, the children had to select the “living environment” perspective in the multiperspective hypermedia environment and then had to detect the chub in the river group (see Figure 2). Another more complex exploration task challenged the children to find out which coral reef fish were simultaneously breaststrokers and plankton-eaters. Here, the children first had either to select the "living environment" perspective or to use the filter button “coral reef” to identify the 11 fish living in the tropical coral reef (see Figure 4).

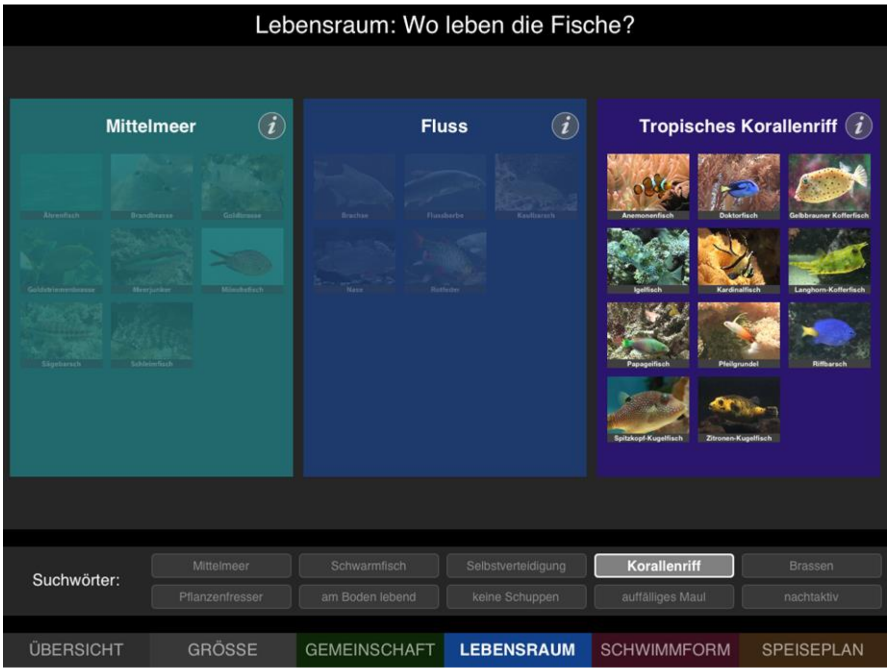

Figure 4. Screen showing the "living environment" perspective from the multiperspective hypermedia environment with an activation of the “coral reef” filter button.

Next, they had to switch to the “swimming style” perspective to figure out the five coral reef fish that were breaststrokers (see Figure 5). Finally, they had to switch to the “eating habits” perspective to find out that three of these fish were simultaneously plankton-eaters (see Figure 6). By asking the children to look up various kinds of information necessary to answer the exploration tasks, we intended to stimulate their perception of (a) different perspectives, (b) the relations between these perspectives, and (c) the relations between the fish within the different perspectives. Therefore, the multiperspective hypermedia environment not only served as a search database but was primarily aimed at stimulating complex learning processes.

Figure 5. Screen showing the "swimming style" perspective from the multiperspective hypermedia environment with an activation of the “coral reef” filter button and the breaststrokers circled in red.

Figure 6. Screen showing the "eating habits" perspective from the multiperspective hypermedia environment with an activation of the “coral reef” filter button and the plankton-eaters that are simultaneously breaststrokers circled in red.

Linear environment. The linear environment, by contrast, was displayed as an illustrated multimedia e-book. Here, the children received the same fish materials as the children in the multiperspective hypermedia environment. However, only information relevant for the exploration tasks was presented, and all information was coherently structured in a fixed linear sequence according to the order of the tasks. Thus, the information necessary for answering the exploration tasks was automatically presented in the correct order. Consequently, it was therein much easier to find the answers for the exploration tasks than in the multiperspective hypermedia environment as there was no need to actively decide how to search for it. Moreover, no active integration of information that was distributed across different information nodes was required as all related information was coherently presented on the same page. Despite the simpler access to information in the linear environment, however, we believe that one disadvantage was that the children received relevant information without being aware of the different perspectives the information belonged to. Consequently, we assumed that this environment would not optimally support the complex learning goal of multiperspective reasoning, which involves realizing and actively choosing different perspectives on domain contents.

Contrary to the multiperspective hypermedia environment, for instance, children in the linear environment did not have to actively search for information about the chub's living environment but rather found this information incidentally on the screen when turning the page after reading the exploration task. Nonetheless, they still had to extract the specific information about the living environment from the text (see Figure 7).

Figure 7. Information screen about the chub in the linear environment with the relevant information (living environment) for the exploration task underlined in red.

For the exploration task about which tropical coral reef fish were simultaneously breaststrokers and plankton-eaters, children were provided with a summary table that allowed them to extract the relevant information. The table contained all tropical coral reef fish and their distributions across the "swimming style" and "eating habits" perspectives (see Figure 8). Again, to identify the three target fish, the children did not have to actively search for the information in the learning environment but just had to extract and integrate the relevant information from the table.

Tropische Rifffische

Fisch	Lebensraum	Schwimmform	Speiseplan	Gemeinschaft	Größe
Anemonenfisch	Korallenriff	Brustschwimmer	Planktonfresser	Einzelgänger	11 cm
Doktorfisch	Korallenriff	Brustschwimmer	Pflanzenfresser	Lockere Gruppe	31 cm
Gelbbrauner Kofferfisch	Korallenriff	Flossenwinker	Schalentierfresser	Einzelgänger	45 cm
Igelfisch	Korallenriff	Flossenwinker	Schalentierfresser	Einzelgänger	50 cm
Kardinalfisch	Korallenriff	Schlängelschwimmer	Planktonfresser	Schwarmfisch	8 cm
Langhorn-Kofferfisch	Korallenriff	Flossenwinker	Schalentierfresser	Einzelgänger	45 cm
Papageifisch	Korallenriff	Brustschwimmer	Schalentierfresser	Lockere Gruppe	25 cm
Pfeilgrundel	Korallenriff	Brustschwimmer	Planktonfresser	Lockere Gruppe	9 cm
Riffbarsch	Korallenriff	Brustschwimmer	Planktonfresser	Schwarmfisch	7 cm
Spitzkopf-Kugelfisch	Korallenriff	Flossenwinker	Schalentierfresser	Einzelgänger	12 cm
Zitronen-Kugelfisch	Korallenriff	Flossenwinker	Schalentierfresser	Einzelgänger	26 cm

Hier siehst du noch einmal eine Übersicht über die verschiedenen **Merkmale der tropischen Rifffische** in deinem Aquarium.

Figure 8. Information screen with a summary table about all tropical coral reef fish and their distributions across the categories of the different perspectives (i.e., living environment, swimming style, eating habits, social behavior, and size) in the linear environment. The relevant information (living environment: coral reef; swimming style: breaststrokers; eating habits: plankton-eaters) and appropriate fish for the exploration task are circled in red.

Measures

Exploration tasks

The exploration tasks were not only implemented to guide students' exploration in the learning environment but also served as dependent variables to assess their exploration performance during the learning phase. The exploration tasks could be divided into *simple* and *complex* exploration tasks. The simple exploration tasks (11 items, α = .61) required the children to select one of the different fish-perspectives in order to find and extract information that was stated at a single node about a specific fish (e.g., “What is the living environment of the chub?”; see also Figures 2 and 7). The complex exploration tasks (six items, α = .61), by contrast, required the children to compare and relate various fish to each other with regard to different perspectives. That is, the children had to integrate information from at least two different conceptual perspectives (e.g., “Which tropical coral reef fish are simultaneously breaststrokers and plankton-eaters?”; see also Figures 4, 5, 6, and 8). The children's answers to the exploration tasks were scored by two blind and independent raters using a coding scheme based on a sample solution (Cohen’s kappa was κ = .92 for the simple exploration tasks and κ = .85 for the complex exploration tasks).

Multiperspective reasoning task

Subsequent to the learning phase, the children were administered a multiperspective reasoning task (three items, α = .69; cf. Piekny & Maehler, 2013), which served as a dependent variable to measure their ability to consider a novel topic from multiple perspectives and to draw elaborated inferences on the basis of these perspectives (Zydney, 2010). On this task, the children were required to transfer their conceptual knowledge about fish biodiversity (i.e., the relation between different fish species with regard to different perspectives) to another topic area; namely, to fantasy animals called *kornikels*. The children obtained hypothetical information about different kornikel species, which also varied with regard to their eating habits, their movements, their living environments, and so on. The information, however, was not provided in a depicted format but as paper-based text so that its inherent multifaceted structure was not as visible as in the multiperspective hypermedia environment. Rather, it had to be inferred by the children themselves. For task accomplishment, children had to address three scientific problems (e.g., “How could you prove that the swimming kornikels are the most aggressive of the kornikel species?”) that challenged them to consider the kornikel species from various conceptual perspectives and to consequently draw specific conclusions about these species (two for each scientific problem). The children’s solutions (in a free-answer format) were scored by two blind and independent raters using a coding scheme that was based on a sample solution (Cohen’s kappa was κ = .80).

Working memory measures

Two of the three WM tasks used (i.e., spatial span, listening span) were adapted from Vock’s (2005) working memory battery. The spatial span task (15 items, α = .77) consisted of figural material; namely, black and white patterns shown in a 3 x 3 matrix. The children had to remember these patterns and simultaneously rotate them mentally, 90° to either the right or left. After a sequence of between one to four patterns, the children had to indicate on a completely white matrix what the rotated patterns would look like. For each item (i.e., each pattern sequence), the number of correctly remembered patterns was divided by the total number of patterns in the sequence so that for each item, a score between zero and one could be achieved. The maximum score was 15.

The listening span task (nine items, $\alpha = .74$) consisted of verbal material. For each item, a sequence of simple sentences were played aloud to the children (e.g., "Humans have a nose," "I see with my ears") who instantly had to identify whether each sentence was "true" or "false." Simultaneously, they had to memorize the last word of each sentence (e.g., "nose," "ears"). After a series of three to six sentences, the children were asked to repeat the final words of the sentences. If any of their decisions about the sentences were incorrect, the item automatically received a score of zero. If all decisions were correct, the score for each item was computed by dividing the number of correctly remembered last words by the total number of last words in the sequence so that a score between zero and one could be achieved for each item. The maximum score was 9.

Finally, as a third WM task, a digit version of a 2-back task (24 items, $\alpha =.76$) was administered (cf. Shallice et al., 2002). A sequence of digits appeared one at a time in the center of the screen. The children were instructed to indicate per key-press for each presented digit whether it was identical to the digit presented two digits before or not. A percentage correct score was computed by dividing the number of correct key-presses by the total number of key-presses required (i.e., 24).

All three WM measures were moderately associated between $r = .25$ and $r = .31$ (all ps $\leq .001$). In order to examine whether they constituted measures of the same construct, we tested for their unidimensionality. A Principal Component Analysis produced a one-factor solution (eigenvalue 1.5) accounting for 50.5% of the total variance. On the basis of this, we used a z-standardized composite score of all WM tasks for further analyses.

Control variables

As control variables, we additionally assessed the children's (a) prior experience and interest in fish and (b) computer experience. Specifically, the children's "prior experience and interest in fish" was assessed with five items ($\alpha = .76$; e.g., "I read much about fish," "I am interested in fish") that were answered on a 4-point Likert scale (1 = *does not apply to me at all* to 4 = *applies to me very much*). On average, the children were moderately experienced and interested in fish (*M* = 2.34, *SD* = 0.60). Furthermore, four questions addressed their "computer experience." These were answered on a 6-point Likert scale (1 = *no experience at all* to 6 = *lots of experience*). Three of the questions addressed the participants' expertise in computer use: (a) expertise in computer use in general (*M* = 3.86; *SD* = 1.12), (b) expertise in computer-based learning programs (*M* = 2.97, *SD* = 1.47), and (c) expertise in computer games (*M* = 3.97, *SD* = 1.40). As the learning environment was implemented on tablet computers, a fourth question concerned the children's experience with tablets (*M* = 2.54, *SD* = 1.52). A mean score was computed for these four items (α = .64).

Procedure

The study consisted of two sessions. In the first session (about 45 min), children completed a few questions about demographic information and their computer experience. Afterwards, the three computer-based WM tasks were administered to each child individually in a random order. Between 1 to 10 days later, the second session (about 90 min) took place with groups of four to 10 children. In this session, all children were randomly assigned to either the multiperspective hypermedia condition (*n* = 97) or the linear condition (*n* = 89). First, the children were asked about their prior experience and interest in fish. Next, to acquaint them with the navigational design of the upcoming learning environment, the children practiced with a training environment about different countries that was structured in the same way as the learning environment to be used (i.e., multiperspective hypermedia environment or linear environment, respectively) until they felt confident about how to use it. Subsequently, the real study phase began with a short introductory film, which invited the children to take on the role of a fish keeper in an aquarium (about 5 min). Importantly, this film provided the children with some general information about fish diversity by giving them an overview of relevant conceptual perspectives on the fish species (e.g., different living environments, eating habits). By providing this information, we wanted to ensure that all children had sufficient prior knowledge about the subject matter so that they could cope with the following task demands. Subsequently, the children individually worked through the assigned learning environment about fish for about 45 min guided by the exploration tasks. This learning phase was divided into four thematically different learning units (e.g., "tropical reef fish" or "special features of fish"). The children were automatically forwarded to the next learning unit after a certain amount of time even if they had not yet finished all exploration tasks. Finally, after completing the learning phase, the children had to work on the multiperspective reasoning task (about 10 min).

Results

Preliminary Analyses

In a first step, we compared the linear and multiperspective hypermedia groups on gender, age, computer experience, prior experience and interest in fish, and WM capacity to ensure that learners in the two groups were similar in their preconditions. As depicted in Table 2, the groups did not differ significantly on any of these variables, indicating that the randomization process resulted in comparable groups of students.

Table 2

Mean Scores (Standard Deviations) and Inferential Statistics for Age, Computer Experience, Prior Experience and Interest in Fish, and the Three WM Measures, as well as Gender Distribution Percentages for the Multiperspective Hypermedia Group and the Linear Group

Measurement (range)		Multiperspective hypermedia group (n = 97)	Linear group (n = 89)	t	p
	Age in years	10.27 (0.45)	10.26 (0.46)	-0.24	.815
	Computer experience (1-6)	3.35 (1.01)	3.32 (0.91)	-0.22	.823
	Prior experience and interest in fish (1-4)	2.33 (0.59)	2.36 (0.62)	0.43	.666
Working memory measures	Spatial span (1-15)	8.50 (2.68)	8.74 (2.65)	0.62	.534
	Listening span (1-9)	5.42 (1.81)	5.83 (1.70)	1.55	.122
	2-back (percentage correct)	70.49 (18.38)	67.05 (17.31)	1.30	.194
	Gender	40.2% female	44.9% female	χ^2 = .43	.514

Descriptive statistics for the simple exploration tasks, the complex exploration tasks, and the multiperspective reasoning task are presented in Table 3 for both groups.

Table 3

Mean Percentage Scores (Standard Deviations) for the Simple Exploration Tasks, the Complex Exploration Tasks, and the Multiperspective Reasoning Task for the Multiperspective Hypermedia Group and the Linear Group

Type of measure	Multiperspective hypermedia group (n = 97)	Linear group (n = 89)
Simple exploration	54.97 (18.07)	54.42 (17.27)
Complex exploration	26.91 (21.49)	50.60 (28.58)
Multiperspective reasoning	37.46 (40.33)	26.97 (32.13)

Table 4 presents correlations for the simple and complex exploration tasks, the multiperspective reasoning task, and WM capacity. WM capacity was moderately correlated with all measures, between r = .32 and r = .42, pointing to the importance of WM capacity as a predictor of students' exploration and multiperspective reasoning performance.

Table 4

Intercorrelations Between the Simple Exploration Tasks, the Complex Exploration Tasks, the Multiperspective Reasoning Task, and WM Capacity

Type of measure	Simple exploration	Complex exploration	Multiperspective reasoning	WM capacity
Simple exploration	-			
Complex exploration	.41**	-		
Multiperspective reasoning	.45**	.24**	-	
WM capacity	.38**	.42*	.32**	-

Note. N = 186.
*p < .05. **p < .01.

The Role of WM for Exploring Multiperspective Hypermedia Environments

In the following, we will present the results according to the respective hypotheses. To test our hypotheses, we conducted moderated linear regression analyses with WM capacity (z-standardized) and learning environment (multiperspective hypermedia coded as 0.5 and linear coded as -0.5) as independent variables and performance on the simple and complex exploration tasks as well as on the multiperspective reasoning task as dependent variables.

Hypotheses 1: WM capacity and exploration performance

For Hypothesis 1a, we expected students high in WM capacity to perform better in the multiperspective hypermedia environment than in the linear environment on the complex exploration tasks but not on the simple exploration tasks. With regard to Hypothesis 1b, by contrast, we did not expect students low in WM capacity to perform better in the multiperspective hypermedia environment than in the linear environment on the simple or on the complex exploration tasks. The linear regression analysis for the simple exploration tasks, $R^2 = 0.16$, $F(3, 182) = 11.87$, $p < .001$, revealed no significant main effect of the learning environment, $B = 0.02$, $SE_B = 0.05$; $t(182) = 0.36$, $p = .720$, but the effect of WM capacity was significant, $B = 0.17$, $SE_B = 0.03$; $t(182) = 5.05$, $p < .001$. Other than expected, this effect was qualified by a significant interaction between WM capacity and learning environment, $B = 0.14$, $SE_B = 0.07$; $t(182) = 2.20$, $p = .029$, indicating that WM capacity moderated the relation between learning environment and performance. In order to probe this interaction, simple comparisons according to the procedure outlined by Aiken and West (1991) were computed for different levels of WM capacity, namely for high WM capacity (defined as 1 *SD* above the sample mean) and low WM capacity (defined as 1 *SD* below the sample mean). The analyses revealed that children with high WM capacity (1 *SD* above the mean) performed significantly better in the multiperspective hypermedia environment than in the linear environment, $B = 0.16$, $SE_B = 0.08$; $t(182) = 2.01$, $p = .045$, whereas for children with low WM capacity (1 *SD* below the mean), there was no difference between the two learning environments, $B = -0.13$, $SE_B = 0.08$; $t(182) = -1.59$, $p = .114$ (see Figure 9).

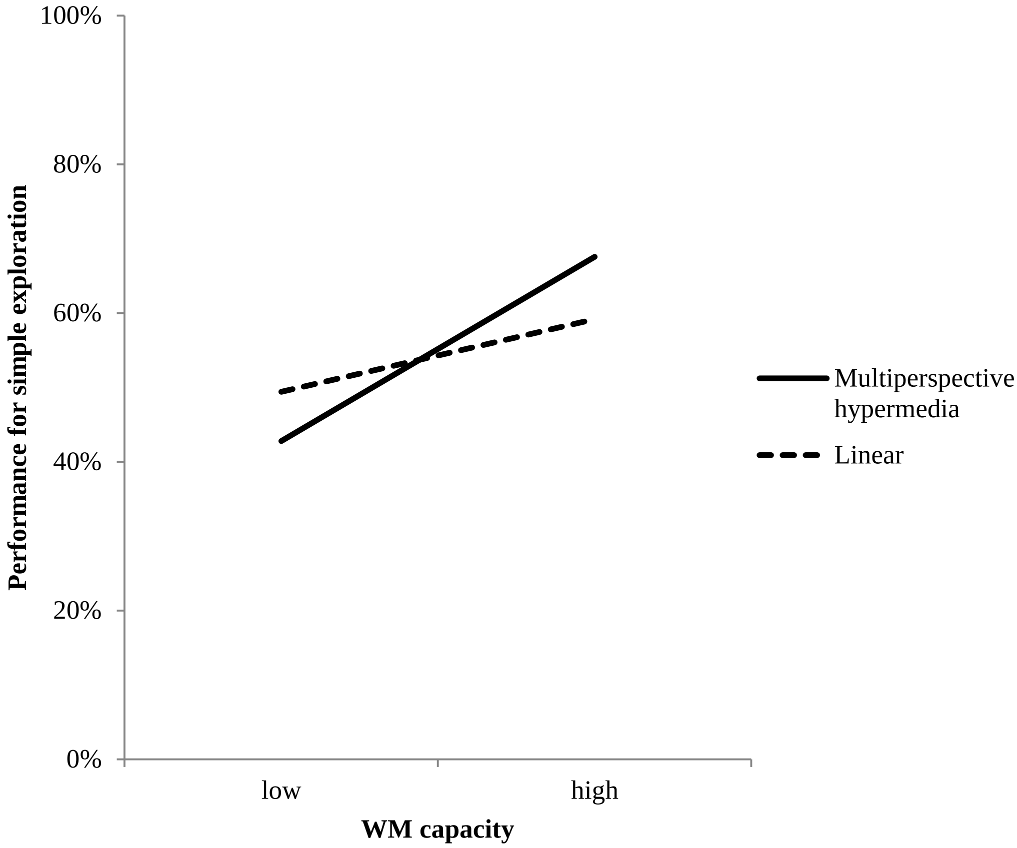

Figure 9. Simple exploration performance in percentage as a function of WM capacity and learning environment (Multiperspective hypermedia vs. Linear).

For the complex exploration tasks, $R^2 = 0.36$, $F(3, 182) = 34.54$, $p < .001$, the linear regression analysis revealed a significant main effect of the learning environment in favor of linear learning, $B = -0.35$, $SE_B = 0.05$; $t(182) = -7.03$, $p < .001$, and a significant positive effect of WM capacity, $B = 0.25$, $SE_B = 0.04$; $t(182) = 7.12$, $p < .001$. Moreover, this effect was qualified by a significant interaction between WM capacity and learning environment, $B = -0.14$, $SE_B = 0.07$; $t(182) = -2.05$, $p = .042$, indicating that WM capacity moderated the relation between learning environment and performance. Unexpectedly, simple comparisons revealed that children with high WM capacity (1 *SD* above the mean) and children with low WM capacity (1 *SD* below the mean) both performed significantly better in the linear environment than in the multiperspective environment, $B = -0.49$, $SE_B = 0.09$; $t(182) = -5.73$, $p < .001$ and $B = -0.20$, $SE_B = 0.09$; $t(182) = -2.33$, $p = .021$. Importantly, this effect was significantly stronger for children high in WM capacity than for children low in WM capacity (see Figure 10).

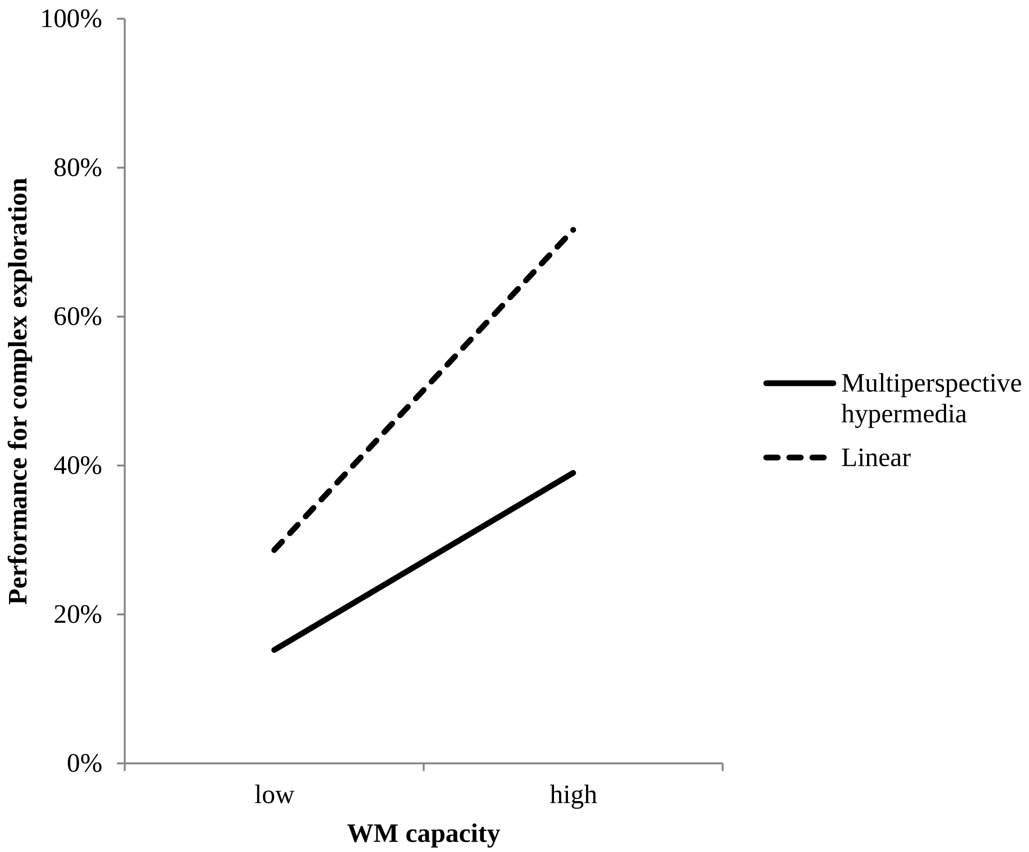

Figure 10. Complex exploration performance in percentage as a function of WM capacity and learning environment (Multiperspective hypermedia vs. Linear).

In sum, Hypothesis 1a – concerning children with high WM capacity – was not confirmed. Whereas these children benefitted more from the multiperspective hypermedia environment than from the linear environment for the simple exploration tasks, we found the reverse effect for the complex exploration tasks. By contrast and in line with Hypothesis 1b, children low in WM capacity never benefitted more from the multiperspective hypermedia environment.

Hypotheses 2: WM capacity and multiperspective reasoning performance

Moreover, we predicted that students with high WM capacity would benefit more from the multiperspective hypermedia environment than from the linear environment in terms of their later ability to engage in multiperspective reasoning about a novel topic (Hypothesis 2a), whereas no benefit from the multiperspective hypermedia environment was predicted for students with low WM capacity (Hypothesis 2b).

For the multiperspective reasoning task, $R^2 = 0.15$, $F(3, 182) = 11.03$, $p < .001$, the linear regression analysis showed a significant main effect of the learning environment in favor of the multiperspective environment, $B = 0.33$, $SE_B = 0.15$; $t(182) = 2.19$, $p = .030$, and a significant positive effect of WM capacity, $B = 0.46$, $SE_B = 0.11$; $t(182) = 4.27$, $p < .001$. Most importantly, these effects were qualified by a significant interaction between WM capacity and learning environment, $B = 0.52$, $SE_B = 0.22$; $t(182) = 2.41$, $p = .017$, indicating that WM capacity moderated the relation between learning environment and performance. Simple comparisons further revealed that children with high WM capacity (1 *SD* above the mean) benefitted more from the multiperspective hypermedia environment than from the linear environment, $B = 0.85$, $SE_B = 0.62$; $t(182) = 3.25$, $p = .001$, whereas for children with low WM capacity (1 *SD* below the mean), there was no difference between the two learning environments, $B = -0.19$, $SE_B = 0.26$; $t(182) = -0.72$, $p = .473$ (see Figure 11), confirming Hypotheses 2a and b.

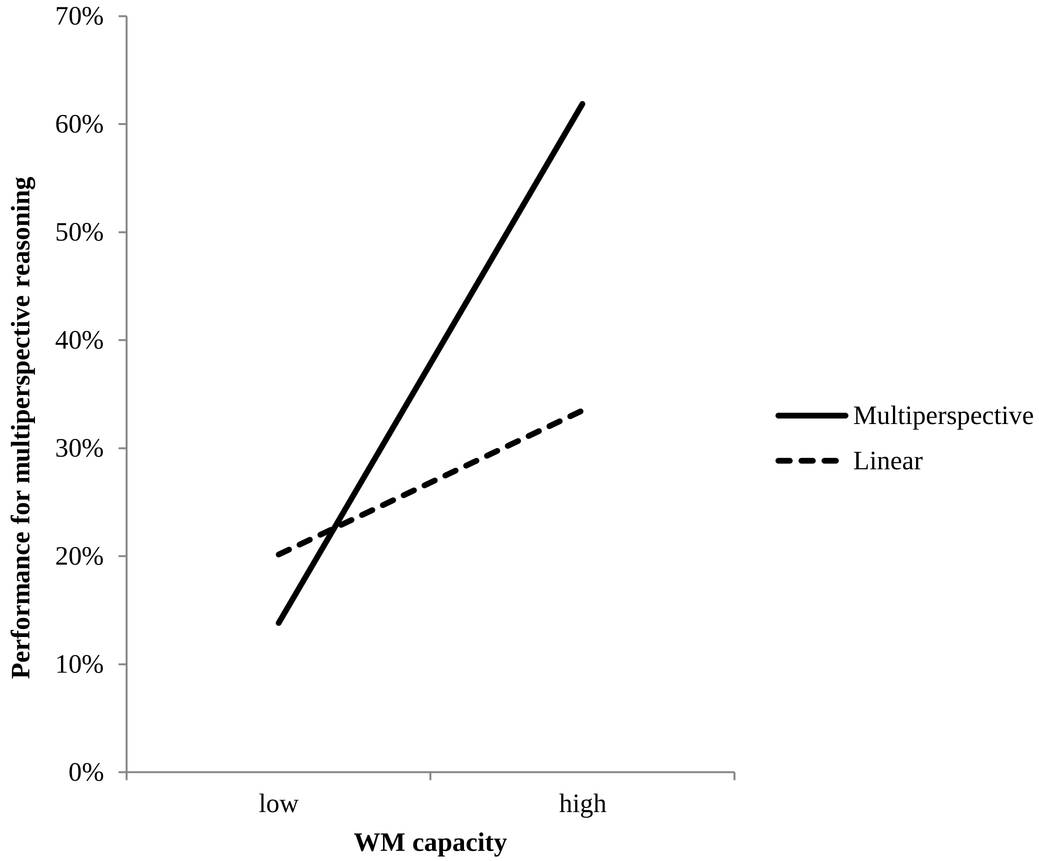

Figure 11. Multiperspective reasoning performance in percentage as a function of WM capacity and learning environment (Multiperspective hypermedia vs. Linear).

Discussion

The present study investigated the role of WM capacity for achieving complex learning goals in a multiperspective hypermedia environment as compared with a linear learning environment. More specifically, multiperspective hypermedia environments should be better for conveying knowledge about multifaceted domains than linear environments on the one hand (Spiro et al., 1992) but should result in a high load on WM resources on the other hand (e.g., Niederhauser et al., 2000). Therefore, we expected that the multiperspective hypermedia environment would be more beneficial than the linear environment for complex learning goals (complex exploration tasks, multiperspective reasoning task) but not for simple learning goals (simple exploration tasks). Importantly however, we expected this to hold only for learners with high WM capacity.

High WM Capacity and Exploration Performance

Unexpectedly, our results for the simple exploration tasks (i.e., the selection of one out of the different conceptual perspectives to find specific information) showed that children high in WM capacity performed better in the multiperspective hypermedia environment than in the linear environment. This was indeed surprising as the multiperspective hypermedia environment was not hypothesized to better support simple exploration goals than the linear environment. Moreover, the information needed to solve the simple exploration tasks was much easier to locate in the linear environment than in the multiperspective hypermedia environment. One reason for this finding might be that for children high in WM capacity, the multiperspective hypermedia environment was more interesting and stimulating for solving these tasks than the linear environment. They may have been bored by the requirements of the linear learning environment (i.e., simply locating target information on the next page) so that they were less motivated to solve such tasks.

For the complex exploration tasks (i.e., the integration of information from at least two different perspectives), by contrast, we found the opposite effect; namely, that learners high in WM capacity performed better in the linear environment than in the multiperspective environment. In fact, all children on average correctly solved only about 25% of the questions in the multiperspective hypermedia environment. Thus, it might be the case that the complex exploration tasks were generally too difficult for the children in the multiperspective hypermedia environment so that even the cognitive resources of children with rather high WM capacity were presumably not sufficient to allow them to successfully engage in this kind of exploration. The complexity of these tasks may have been primarily due to the fragmentation of information in the multiperspective environment screens. Although this fragmentation was intended to emphasize multiperspectivity, it may have strongly reduced coherence between the pieces of the to-be-integrated information (Shapiro & Niederhauser, 2004; Van Dijk & Kintsch, 1983) and may have additionally imposed memory demands that were too high (e.g., due to split-attention effects by which learners had to divide their attention between different sources of to-be-integrated information; cf. Cierniak, Scheiter, & Gerjets, 2009). This might have made it much more difficult for the children to infer associations between different pieces of information than in the linear environment. Particularly, whereas in the linear environment, all information necessary for answering a complex exploration task was presented on the same page, the necessary information in the multiperspective hypermedia environment had to be collected by accessing at least two different perspectives. Consequently, children in the multiperspective hypermedia environment had to switch between different perspectives, memorize rather difficult information patterns from those perspectives (e.g., “Which tropical coral reef fish are breaststrokers?”; “Which tropical coral reef fish are plankton-eaters?”), and integrate these pieces of information from memory when answering the complex exploration tasks (e.g., “Which tropical coral reef fish are simultaneously breaststrokers and plankton-eaters?”). The poor performance of children using the multiperspective hypermedia environment in answering these complex exploration tasks is in line with results by Niederhauser and colleagues (2000) who found in a multiperspective hypertext experiment that the more the students had to switch and compare between web pages, the worse were their learning outcomes.

In conclusion, the exploration performance for learners with high WM capacity in multiperspective hypermedia environments probably strongly depends on the difficulty of the exploration task. Accordingly, multiperspective formats can be either stimulating (e.g., with regard to simple exploration tasks) or cognitively overtaxing when information that needs to be integrated is distributed across different pages (e.g., with regard to complex exploration tasks). In the latter case, well-prepared linear materials that support the coherence of information seem to be more appropriate, at least for young learners. Still, performance in the linear environment was also highly related to WM capacity. Thus, the extraction and integration of information from tabular representations appeared to require high WM resources in the linear environment as well.

High WM Capacity and Multiperspective Reasoning Performance

Most importantly and beyond the issue of exploration performance, the present study revealed that the multiperspective hypermedia environment was more beneficial for later engagement in multiperspective reasoning than the linear environment, at least when sufficient cognitive resources in terms of WM capacity were at students' disposal. That is, even though the exploration of to-be-integrated information was better in the linear environment, the multiperspective hypermedia environment was found to better support children's later ability to engage in multiperspective reasoning. Although the potential of a multiperspective format for stimulating multiperspective reasoning has already been the subject of investigation (Fitzgerald et al., 1997; Zydney, 2010), a specific comparison with a standard linear format had not previously been performed. In our study, this comparison revealed that the potential of multiperspective formats is even generalizable to a young population such as elementary school children.

Low WM Capacity and Multiperspective Hypermedia Environments

As expected, students low in WM capacity never benefitted more from the multiperspective hypermedia environment than from the linear environment, neither in terms of their exploration performance (simple and complex exploration tasks) nor in terms of their multiperspective reasoning. Therefore, demanding instructional formats such as multiperspective hypermedia instruction might not provide an appropriate way to stimulate complex learning goals for learners low in WM capacity.

Limitations and Outlook

With regard to our findings, it should be noted that the sample was limited to fourth-graders. Although we intentionally aimed to investigate the potential of multiperspective instruction for a young school population due to its practical relevance, it would be interesting to consider older students as well. In older students, WM capacity might be further developed so that a more elaborated approach to multiperspective hypermedia environments and in turn a better integration of different perspectives could be expected. Moreover, our results might not generalize to traditional computer-based learning environments as we intentionally used touch-screen interfaces. Therefore, future research should examine whether the current results can also be obtained for older students and for mouse-controlled learning environments.

Second, although we tried to develop a multiperspective hypermedia environment that would best support exploration and learning processes, it might have been too complex as learners were apparently overwhelmed by the complex exploration tasks in the multiperspective hypermedia environment. When dealing with the simple exploration tasks, by contrast, the multiperspective hypermedia environment might have been more stimulating for children high in WM capacity than the linear environment. Therefore, future studies are needed to shed light on these unexpected results. Specifically, prospective studies should investigate the effectiveness of multiperspective hypermedia environments with an even more supportive design and should replicate the current study while assessing children's motivation to engage in either of the two learning environments. Moreover, in a replication study, it would also be interesting to use a third condition with a linear environment that either asks learners to integrate information from different pages when answering a complex exploration task or provides an overview of the different perspectives. That is to say, investigating a linear condition with integration demands would help to explain the mediocre results in the multiperspective hypermedia environment for the complex exploration questions; namely, whether they were due to the demands from the integration of information or due to the network-like structure of the nonlinear environment. Moreover, providing an overview of the different perspectives in the linear condition might shed light on the beneficial effect of the multiperspective hypermedia environment for later multiperspective reasoning; namely, whether this was due to the processing of the overall organization of information or to the free exploration of information in the multiperspective hypermedia environment.

In sum, our study provides initial evidence for the stimulating role of multiperspective hypermedia formats for elementary school children with high WM capacity. In the next step, more fine-grained analyses (e.g., log file analyses) that focus on processing strategies during learning with multiperspective formats should be performed. Such analyses may disclose which processing strategies can explain the performance differences between learners high and low in WM capacity.

Conclusion

To conclude, according to the present findings, WM capacity represents an important learner precondition when dealing with multiperspective hypermedia environments, particularly when the aim is to stimulate complex learning goals such as multiperspective reasoning. However, an unrestrained application of multiperspective hypermedia environments in school classes is not advisable as they are not generally beneficial but rather show differential effectiveness depending on students' learning prerequisites and the specific task demands. Particularly when dealing with exploration tasks that require information integration and evoke split-attention effects, multiperspective hypermedia environments seem to be rather difficult to handle for all ability groups. Still, for learners with high WM capacity, the exploration of multiperspective hypermedia environments seems to provide an effective approach that stimulates their later multiperspective reasoning abilities.

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4

How Children Navigate a Multiperspective Hypermedia Environment: The Role of Working Memory Capacity

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Abstract

The use of hypermedia environments is increasing in school education. The interactivity in hypermedia environments challenges learners to autonomously navigate such environments. Particularly in multiperspective hypermedia environments (MHEs), which emphasize the multiperspectivity of a topic, it is important to apply navigational behaviors that exploit the advantages of this way of structuring information through which different perspectives can be selected and compared. However, we assume that the availability of sufficient working memory (WM) resources is an important precondition for effectively engaging in this type of perspective processing. The present study examined $N = 97$ fourth-graders' navigational behaviors during hypermedia learning and their relation to WM and performance. Our results confirmed that WM was positively related to perspective processing, which was positively related to performance. Mediation analyses revealed that perspective processing partially explained the relation between WM and performance. To conclude, WM and perspective processing are both important for benefitting from MHEs.

Keywords: navigational behavior, working memory, hypermedia learning, cognitive flexibility theory, elementary school children

How Children Navigate a Multiperspective Hypermedia Environment: The Role of Working Memory Capacity

Digital learning technologies such as instructional hypermedia environments enable innovative and interactive learning approaches to be used (e.g., Falloon, 2013). Instructional hypermedia environments, for instance, display multimedia materials (e.g., text, pictures, videos) in a nonlinear structure (e.g., hierarchical or networked). Particularly networked hypermedia structures are supposed to be appropriate for emphasizing the complexity of multifaceted knowledge domains that present the same content materials in a variety of different contexts (Jacobson & Spiro, 1995; Spiro & Jehng, 1990). As this type of hypermedia environment requires learners to simultaneously consider multiple viewpoints, it can also be referred to as a multiperspective hypermedia environment (MHE; cf. Lima, Koehler, & Spiro, 2002). Compared with traditional learning materials (e.g., textbooks) that have a linearly structured sequence, (multiperspective) hypermedia environments allow learners to autonomously navigate learning materials in a nonlinear fashion. More specifically, learners can decide what information to explore next and how to process this information (e.g., as text or videos). Although several studies have already examined which navigational behaviors might be effective for hypermedia learning in general (e.g., Lawless & Kulikowich, 1996), effective navigational behaviors in hypermedia environments that particularly emphasize the multiperspectivity of a knowledge domain (i.e., MHE) have received less attention. Moreover, we argue that effective navigation in MHEs requires a large amount of working memory (WM) resources (e.g., Baddeley, 2012) such that not all learners are able to apply navigational behaviors that maximize their learning. To the best of our knowledge, this issue has not yet been empirically tested.

On the basis of this state of affairs, the present study focused on the relations between WM capacity, navigational behaviors, and performance in the context of multiperspective hypermedia learning. More precisely, we investigated which specific navigational behaviors are beneficial for learning when dealing with an MHE. Moreover, we examined the association of WM capacity with navigational behaviors and performance in MHEs. We investigated these research issues in a sample of school children because innovative instructional environments (e.g., MHEs) are currently commonly advocated in the educational context (e.g., Falloon, 2013). Particularly, given the increasing interest in tablet computers, which seem to be more intuitive for younger children to handle than traditional computers (Lane & Ziviani, 2010), an application of such environments can also be found among elementary school children. Thus, it is particularly interesting to focus on how these environments can be used by this population.

Hypermedia Learning

Hypermedia environments are information systems containing multiple information nodes that are interconnected in a nonlinear fashion. Moreover, the information is displayed in different representational formats such as text, pictures, or videos (Scheiter & Gerjets, 2007). Navigating the nonlinear structure of hypermedia environments involves a high degree of learner control because not only can learners choose what information to access, but they can also decide the order and the format they prefer to process it in (e.g., as text or video). Generally, one can differentiate between two types of hypermedia structures: hierarchical and networked (DeStefano & LeFevre, 2007). In hierarchical hypermedia environments, the interconnections between information nodes can be described as a tree structure with broader topics at higher levels and subordinate topics at lower levels. Networked hypermedia environments, by contrast, have a nonsequential structure that is characterized by associative links relating semantically similar information in the environment. According to the framework of cognitive flexibility theory (Jacobson & Spiro, 1995; Spiro & Jehng, 1990), networked hypermedia environments are ideal for displaying multifaceted knowledge domains that present the same content materials in a variety of different contexts. If these networked hypermedia environments are designed in a way that allows learners to simultaneously consider multiple viewpoints, they can also be referred to as multiperspective hypermedia environments (MHEs; cf. Lima et al., 2002). As an example of an MHE, Jacobson and Spiro (1995) asked learners to consider the impact of technology on 20th-century society and culture from multiple perspectives such as progress-problems, freedom-control, or technological efficiency. The content materials were displayed in a multiperspective hypermedia structure, thus making it easier for learners to consider them from different conceptual perspectives.

The autonomous “criss-crossing of the conceptual landscape” in MHEs is assumed to support constructive information processing so that a deeper elaboration of the learning material and a better comprehension of multifaceted topics can take place. Moreover, learners are supposed to develop more flexible cognitive structures that enable them to transfer acquired knowledge elements to novel problem contexts (Jacobson & Spiro, 1995). To benefit from these advantages, it can be assumed that MHEs (as well as hypermedia environments in general) require learners to engage in effective navigational behaviors. However, not all navigational decisions support comprehension and learning (e.g., Lawless & Kulikowich, 1996). The next section reviews differences in navigational behaviors concerning their effectiveness for exploring hypermedia environments.

Navigation in Hypermedia Environments

In the last two decades, various studies with both children and adults have investigated the effectiveness of navigational behaviors when learners explore (hierarchical or networked) hypermedia environments (e.g., Lawless, Brown, Mills, & Mayhall, 2003; Naumann, Richter, Christmann, & Groeben, 2008; Richter, Naumann, Brunner, & Christmann, 2005; Puntambekar & Goldstein, 2007; Salmerón & García, 2011; Salmerón, Baccino, Canas, Madrid, & Fajardo, 2009). Richter and colleagues (2005), for instance, demonstrated that more linear sequencing and less backtracking behavior (clicking backwards) produced more systematic navigational behavior and fewer orientation problems and were in turn related to higher learning outcomes. Salmerón and colleagues (2009) and Salmerón and García (2011) presented learners with a graphical overview of a hierarchical hypertext structure and found that initial processing of the overview best benefitted comprehension of the hypertext. In addition, choosing a coherent navigational path (i.e., subsequently navigating through semantically related pages) and focusing on task-relevant pages were also associated with better comprehension and learning (Lawless et al., 2003; Lawless & Kulikowich, 1996, 1998; Naumann et al., 2008; Puntambekar & Goldstein, 2007; Salmerón & García, 2011). By contrast, learners who spent more time interacting with the special features of the hypermedia environment (e.g., movies, animations, graphics) or whose navigational path revealed no logical order showed lower comprehension and learning performance (Barab, Bowdish, Young, & Owen, 1996; Lawless & Kulikowich, 1996; Lawless, Mills, & Brown, 2002).

Thus, navigational behaviors such as focusing on task-relevant pages and choosing a coherent or linear navigational path seem to be most effective for learning in (hierarchical and networked) hypermedia environments. However, in networked hypermedia environments that particularly emphasize the multiperspectivity of a knowledge domain, namely in MHEs (cf. Lima, et al., 2002), it might not be sufficient to review task-relevant contents in one systematic sequence because MHEs are not primarily designed to convey isolated factual knowledge in a specific order. Rather, they aim to convey broad conceptual knowledge about a topic, that is, an overview and understanding about how different contents are related to each other from different conceptual perspectives (e.g., Jacobson & Spiro, 1995). For this reason, usually two types of navigational choices can be distinguished in MHEs; namely, the processing of perspectives and the processing of content. More precisely, on the one hand, the processing of perspectives implies the selection of conceptual overview pages that display the linking structure of the content nodes within different perspectives (perspective processing). On the other hand, the processing of content implies the selection of a specific content page (e.g., a text or video) without taking the context (i.e., the linking structure of the content nodes within different perspectives) into account (content processing). In the context of MHEs, perspective processing should arguably be more effective than content processing for acquiring conceptual knowledge. Indeed, although content processing is not considered to be ineffective as it does not hamper learning, it is also not considered to be effective, as this navigational behavior does not face the challenges of an MHE (i.e., acquiring conceptual overview knowledge). Beyond the navigational behaviors of perspective processing and content processing that are defined as task-relevant navigational behaviors (i.e., navigational behaviors addressing a given learning task), irrelevant navigational processing is also likely to occur in nonlinear settings. Irrelevant processing (i.e., navigational behaviors that do not address a given learning task) can result from distraction or disorientation in these learning environments (e.g., Scheiter & Gerjets, 2007). In line with previous research (e.g., Lawless & Kulikowich, 1996), irrelevant processing is likely to be ineffective in the context of MHEs for comprehension and learning. To the best of our knowledge, the effectiveness of these navigational behaviors (i.e., perspective processing, content processing, irrelevant processing) in MHEs has not yet been explicitly investigated. Therefore, one goal of the present study was to address this issue in a sample of elementary school children using an MHE.

However, although the selection of conceptual overview pages to compare and relate various contents from different perspectives (perspective processing) is assumed to be effective, it also demands a great deal of cognitive and metacognitive resources (cf. Niederhauser, Reynolds, Salmen, & Skolmoski, 2000; Scheiter & Gerjets, 2007). Consequently, not all learners will be able to engage in effective perspective processing. As we argue next, an important learner characteristic that might be positively related to the effective use of this navigational behavior is working memory capacity.

The Role of Working Memory Capacity in Hypermedia Navigation

Working memory (WM) is a subsystem of human memory that primarily consists of two simultaneous functions: the temporary storage of information and the executive control of information processing (Baddeley, 2012). The storage of information is assumed to take place in different slave systems, either in the visual cache for visuo-spatial information or in the phonological store for verbal information (e.g., Baddeley & Logie, 1999). Concurrent information processing, by contrast, can be ascribed to the executive control, which can be decomposed into various executive functions such as focusing attention while inhibiting irrelevant information, dividing attention between two important stimuli, making decisions, or switching between tasks (Baddeley, 2012; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000).

WM has been shown to be positively associated with a variety of learning outcomes such as school achievement in general or reading comprehension in particular (e.g., Alloway & Alloway, 2010; Seigneuric & Ehrlich, 2005). The impact of WM capacity has also been theoretically discussed in the context of hypermedia learning (Lowrey & Kim, 2009; Niederhauser et al., 2000) and has been empirically demonstrated (Lee & Tedder, 2003; Pazzaglia, Toso, & Cacciamani, 2008). However, the association of WM capacity and navigational processing in hypermedia environments has received less attention. To the best of our knowledge, there is only one study that (indirectly) related WM capacity to navigational behaviors in a hypertext setting (Naumann et al., 2008). Specifically, the authors found that students with higher WM capacity benefitted more from a hypertext strategy training in terms of their learning outcome than students with lower WM capacity and that this effect was partially mediated by task-related navigational behaviors. However, the direct relation of WM capacity to navigational behaviors in hypermedia environments in general, or in MHEs in particular, has yet to be investigated.

On a theoretical level, WM—especially its executive control—is likely to be involved in a variety of navigational processes such as dividing attention between co-occurring information, making decisions about link selection, or deciding about how to process information (cf. McDonald & Stevenson, 1996; Niederhauser et al., 2000). Particularly navigational behaviors associated with perspective processing, such as switching between different conceptual perspectives and flexibly restructuring one’s knowledge, require many WM resources (Diamond, 2013; Niederhauser et al., 2000). Consequently, only learners who possess sufficient WM resources will be able to effectively apply perspective processing with regard to learning. Furthermore, in order to avoid irrelevant processing, learners are challenged to focus their attention and inhibit distracting information. These processes are also associated with WM resources (e.g., McDonald & Stevenson, 1996). Therefore, it is reasonable to expect learners with high WM resources to be able to avoid irrelevant processing, whereas learners with low WM resources should show high levels of irrelevant processing. Finally, the navigational behavior of content processing should neither be expected to characterize learners with high WM capacity, who might rather engage in perspective processing, nor learners with low WM capacity, who might rather engage in irrelevant processing.

Taken together, another goal of the present study was to investigate the relation of WM capacity to navigational behaviors in an MHE. Specifically, we expected WM capacity to be positively related to perspective processing and negatively related to irrelevant processing. By contrast, the navigational behavior of content processing was not expected to be significantly related to WM capacity.

The Present Study

The present study focused on the relation between WM capacity, navigational behaviors, as well as exploration performance and learning outcomes in a sample of elementary school children dealing with an MHE. Specifically, we addressed the following four hypotheses:

First, we wanted to replicate previous findings regarding the positive effect of WM capacity on learning in hypermedia environments (e.g., Pazzaglia et al., 2008) for elementary school children. Consequently, we predicted that WM capacity would be positively related to children's exploration performance and learning outcomes when working in an MHE (Hypothesis 1).

Second, we addressed whether WM capacity would be associated with students' navigational behaviors. We hypothesized that WM capacity would be positively related to perspective processing and negatively related to irrelevant processing. By contrast, we expected that WM capacity would not be associated with content processing (Hypothesis 2).

Third, we addressed the extent to which the different navigational behaviors could be considered effective with regard to children's exploration performances and learning outcomes. Whereas we expected perspective processing to be positively and irrelevant processing to be negatively associated with children's performance, we expected that content processing would not be associated with performance (Hypothesis 3).

Finally, we aimed to investigate whether the assumed positive association between WM capacity and performance in (multiperspective) hypermedia environments could be explained by the use of effective navigational behaviors. Specifically, we hypothesized that the relation between WM capacity and performance would be mediated by perspective processing (Hypothesis 4).

Method

Participants

The sample consisted of 97 fourth-graders (40.2% female) from four different elementary schools in Baden-Württemberg, Germany. The children's ages ranged from 9 to 12 years (*M* = 10.3, *SD* = 0.45). Active parental approval for participation was obtained for all children.

Materials

Learning domain and exploration tasks

We designed an MHE on the "biodiversity of fish" for the present study (see Kornmann et al., 2012). The biological topic of "biodiversity" implies that a diversity of species is presented along a number of important conceptual perspectives such as their living environment or their eating habits (Lindemann-Matthies, 2005). Thus, it qualifies as an appropriate topic for MHEs. For the children, the fish topic was embedded in an aquarium setting that invited them to take on the role of a fish keeper. To adequately fulfill their role, they had to learn about 24 different fish species, for instance, about where they live or how they swim. To support the exploration of the fish environment, we provided the children with topic-exploration tasks that guided them through the learning phase. Importantly, these tasks aimed to convey a conceptual overview of knowledge about the topic by motivating the children to select different perspectives in order to find information (for further details on the exploration tasks, see 2.2.2 and 2.3.2).

Multiperspective hypermedia environment (MHE)

We developed the MHE for a tablet computer because touch-screen interfaces are viewed as better adapted to the skills of younger children who find it more difficult to use a traditional computer (Lane & Ziviani, 2010). The first page of the MHE was an overview of 24 alphabetically ordered fish species represented with pictures (see Figure 1). Clicking on a specific fish picture enlarged the picture and produced two hyperlinks that allowed the children to engage in content processing by either reading additional text or watching a video about the fish. Furthermore, the alphabetical overview screen contained six colored hyperlinks that allowed access to six information pages representing the available perspectives according to which the fish could be explored (i.e., alphabetical overview, size, living environment, eating habits, social behavior, and swimming style).

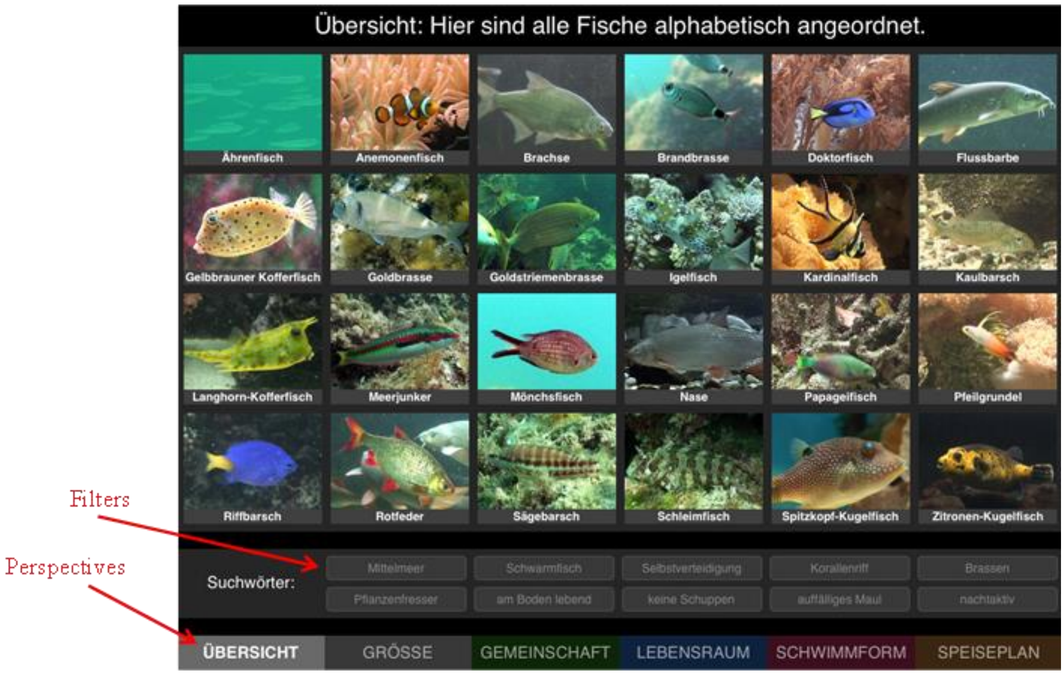

Figure 1. Overview page of the MHE with all 24 fish ordered alphabetically, with hyperlinks for the different fish-perspectives and for filtering.

By clicking on one of these fish-perspective hyperlinks, the alphabetical order of the fish was reordered according to the categories corresponding to a particular perspective (see Table 1 for all categories).

Table 1

Overview of All Perspectives With the Corresponding Categories From the MHE

Perspectives	Categories		
Alphabetical overview	-	-	-
Size	-	-	-
Social behavior	Swarm	Loner	Loose group
Living environment	Mediterranean Sea	River	Tropical reef
Swimming style	*Snaky-swimmer* (sub-carangiform)	*Breaststroker* (labriform)	*Finny-waver* (tetraodontiform)
Eating habits	Plant-eater	Plankton-eater	Shellfish-eater

For example, by clicking on the “living environment” hyperlink, all fish were sorted into one of the three categories “river,” “Mediterranean Sea,” or “tropical coral reef” (see Figure 2).

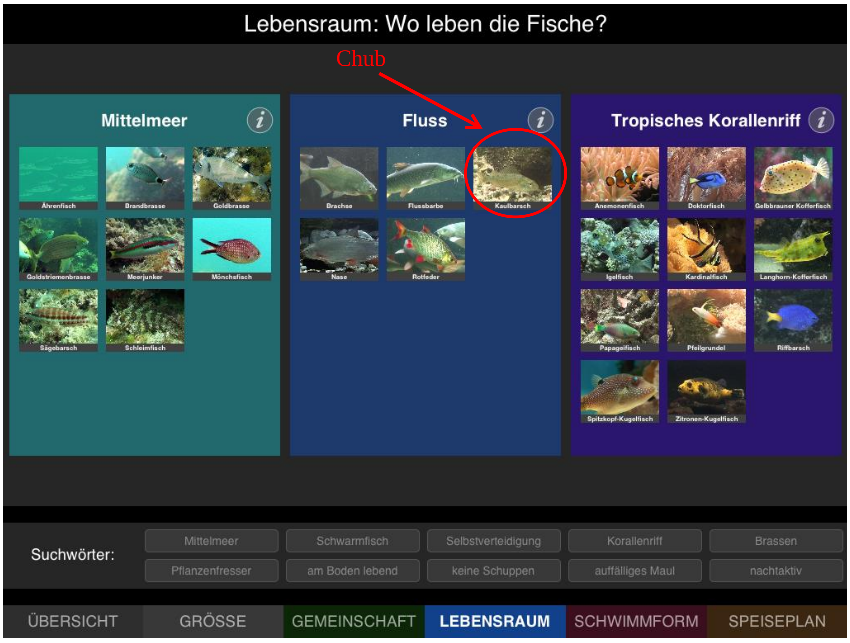

Figure 2. "Living environment" perspective page from the MHE with all fish sorted into the categories "Mediterranean Sea," "river," and “tropical coral reef" (the chub is circled in red, see exploration task).

Thus, clicking on the perspective hyperlinks and comparing how the fish were subsequently reordered helped the children to engage in perspective processing. Finally, different hyperlinks provided filtering (e.g., fish without scales) and could be used to highlight a subgroup of fish, thus allowing the children to consider the fish from different angles to stimulate perspective processing. Each perspective page allowed access to all fish and to the hyperlinks for the different fish-perspectives and for filtering (see Figure 3 for an exemplary extract of the structural associations between perspectives and contents in the MHE).

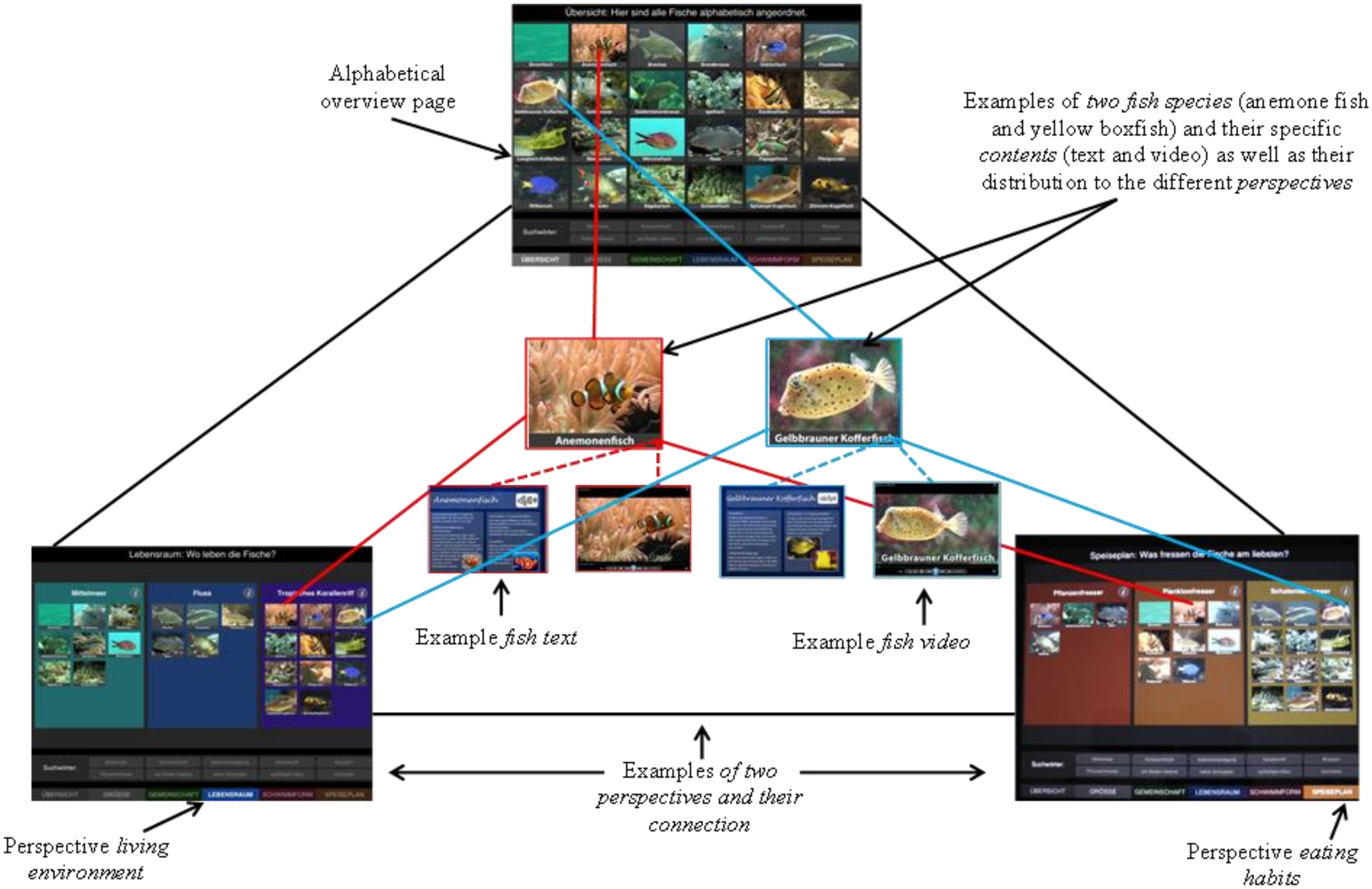

Figure 3. Extract of the structural associations between two exemplary fish (anemone fish and yellow boxfish) and three exemplary perspectives (alphabetical overview, living environment, eating habits).

For example, one exploration task asked the children to figure out the living environment of the chub. To answer this question, the children had several options for exploration. On the one hand, they could use a perspective processing strategy by selecting the “living environment” perspective and then by detecting that the chub belonged to the "river" category (see Figure 2). On the other hand, they could engage in a content processing strategy by clicking on the picture of the chub and could extract the relevant information either by reading the additional text or by watching the video about the chub (see Figure 4).

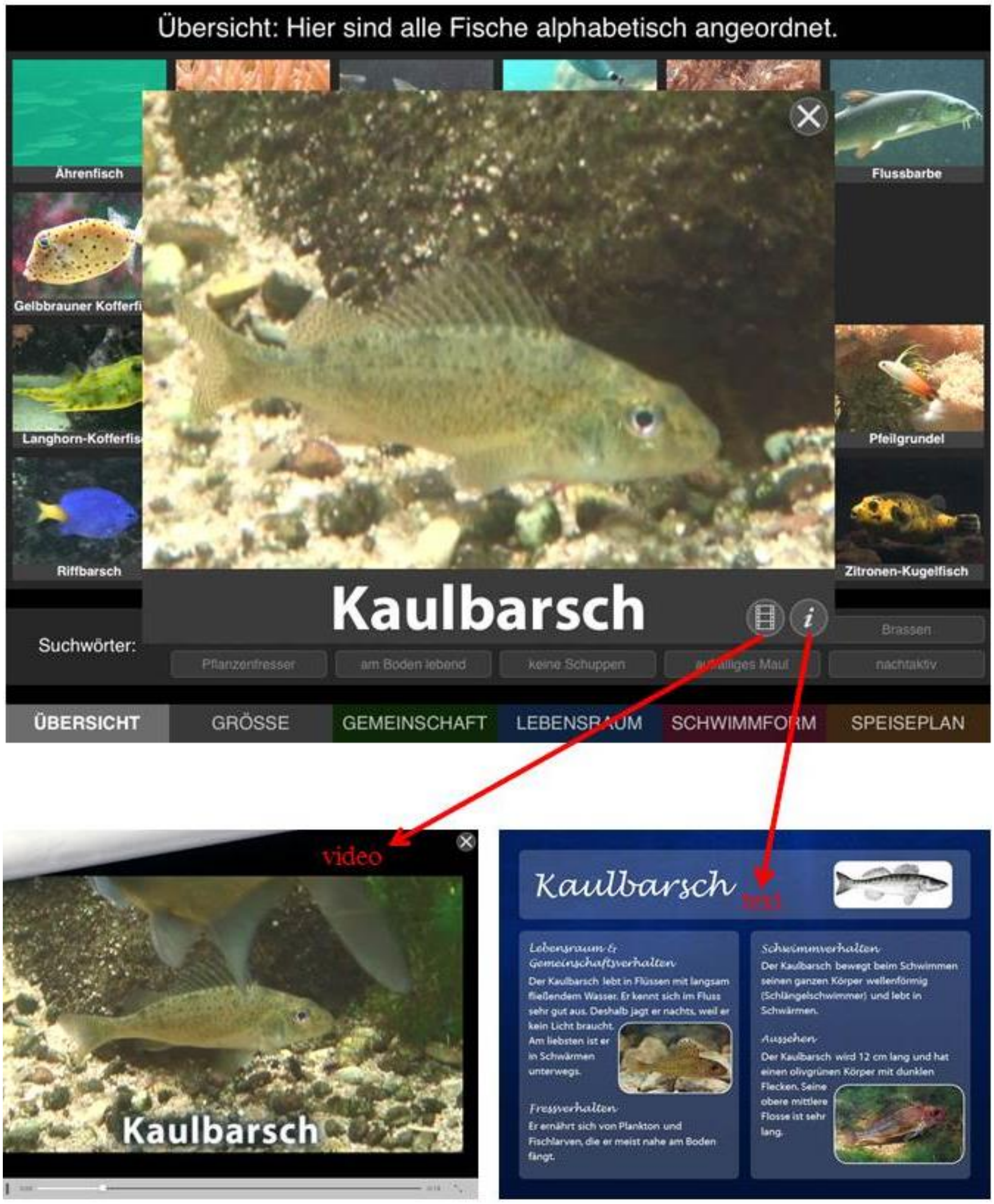

Figure 4. Overview page of the MHE with the picture of the chub enlarged. Clicking on one of the two hyperlinks in the bottom right corner of the picture allows the user to either read additional text or watch a video about the chub.

Another exploration task challenged the children to compare two “plant-eater” fish, namely the nase fish and the surgeon fish. Again, to solve this task, on the one hand, children could select the different perspectives (e.g., living environment) and compare the two fish according to their category classification (e.g., river vs. tropical reef; perspective processing). To facilitate and clarify the comparison, they could additionally use the filter “plant eaters” to highlight only this subgroup of fish (see Figure 5). On the other hand, the children could thoroughly study both fish individually for a comparison by sequentially reading the specific texts about the two fish or by watching the corresponding videos (content processing).

Figure 5. "Swimming style" perspective page from the MHE with an activation of the filter “plant eaters” and the nase fish and the surgeon fish circled in red.

Measures

Navigational behaviors

We analyzed the log files produced by the iPad application to identify the navigational behaviors of the students (i.e., perspective processing, content processing, and irrelevant processing). First, we determined whether students’ actions represented on-task behavior (i.e., navigational behavior that was aimed at solving one of the exploration tasks). For this purpose, a set of rules was specified for each of the tasks, and these rules were matched against the action sequences of a student. Moreover, the specification of each task-dependent rule consisted of two steps: (a) which single actions were potentially relevant for a task and (b) whether a sequence of actions completely covered the task. The second step, associating sequences of actions with a task, was more complicated as students could use different strategies, namely perspective processing and content processing. Moreover, perspective processing was associated with the switching between different perspectives without a fixed order so that it was difficult to determine whether the chosen navigational sequence was actually task-related. Thus, for most tasks, the rules involved both a deterministic part (the expected action elements) and some heuristics (order and frequency of actions).

Applying the rules for all exploration tasks to all action sequences for each individual action resulted in a decision about whether the action was associated with on-task or off-task navigational behavior and whether it was related to perspective processing or content processing. In this way, we identified the three navigational behaviors previously announced; namely, perspective processing, content processing, and irrelevant processing. Specifically, perspective processing included all on-task navigational behaviors associated with considering the fish from different angles to gain a conceptual overview of the fish topic: total time spent on conceptual perspective pages (e.g., swimming style) and total time of filter use (e.g., plant eaters). Content processing, by contrast, included all on-task navigational behaviors associated with the processing of specific topic materials: total time spent reading texts and total time spent watching videos. Finally, irrelevant processing included all navigational behaviors that did not help to solve an exploration task (e.g., watching irrelevant videos, using irrelevant filters).

Exploration performance

The exploration tasks were not only implemented to stimulate children to select different perspectives for the purpose of conveying conceptual overview knowledge, but also served as dependent variables for their exploration performance during the learning phase. The exploration tasks (21 items; $\alpha = .74$) asked the children either to find information about specific fish (e.g., “What is the living environment of the breams?”) or to compare and interrelate different fish with each other (e.g., “Which features differ between nase fish and surgeon fish?”). The children's answers to these questions were scored by two blind and independent raters (Cohen’s kappa was $\kappa = .92$).

Learning outcomes

Subsequent to the learning phase, a posttest including *inferential questions* and *scientific transfer questions* was administered to the children to measure their learning achievement. The inferential questions (11 items, α = .59) asked the children to combine different facts from their recently acquired fish knowledge and to subsequently draw conclusions (e.g., “Which fish do not need a well-lighted place for their aquarium? Why?”). The scientific transfer questions (seven items, α = .83), by contrast, asked the children to transfer the conceptual knowledge that they had acquired about fish biodiversity (i.e., the relation between different perspectives or different fish) to another subject area; namely, to fantasy animals called *kornikels*. More specifically, this task challenged them to consider the kornikels from different perspectives. However, the information was not provided in a depicted format but as paper-based text so that its inherent multifaceted structure was not as visible as in the MHE. Specifically, the different kornikel species also varied with regard to their eating habits, their movements, their living environments, and so on. The children had to use this information to solve complex tasks that challenged them to relate different pieces of information about the kornikel species and to subsequently draw elaborated and scientific inferences (e.g., “How could you prove that the swimming kornikels are the most aggressive of the kornikel species?”). The children’s free answers to the inferential and scientific transfer questions served as dependent variables representing their learning performance and were again scored by two blind and independent raters (Cohen’s kappa was κ = .88 for the inferential questions and κ = .83 for the scientific transfer questions).

Working memory measures

Children’s WM capacity was measured with three WM tasks. Two of the three WM tasks (spatial span, listening span) were adapted from Vock’s (2005) working memory battery for children. The spatial span task (15 items, α = .79) contained figural material; namely, black and white patterns shown in a 3 x 3 matrix. The children had to memorize these patterns and simultaneously rotate them mentally, 90° either to the right or left. After a sequence of between one to four patterns, the children had to specify what the rotated patterns would look like on a white matrix. The listening span task (nine items, α = .72), by contrast, contained verbal material. Children listened to a sequence of simple sentences (e.g., “Humans have a nose,” “I see with my ears”) and directly had to indicate whether each sentence was “correct” or “wrong.” Concurrently, they had to remember the last word of each sentence. After a series of three to six sentences, the children were asked to repeat the final word of each sentence.

Last, as a third WM task, the children had to deal with a numerical version of a 2-back task (24 items, $\alpha = .78$; cf. Shallice et al., 2002). Herein, the children observed a sequence of digits that appeared one after another at the center of the screen and were instructed to indicate per key-press whether each digit was identical to the digit that appeared two digits before or not.

All three WM tasks were moderately associated between $r = .28$ and $r = .45$ (all ps < .01). To test whether the three tasks measured the same underlying ability, we conducted a principal components analysis. The analysis produced a one-factor solution (eigenvalue 1.7) that accounted for 56.2% of the total variance so that the unidimensionality of the tasks could be assumed. Based on this, we used a z-standardized composite score of all WM tasks in all further analyses.

Procedure

The study comprised two sessions. In the first session (about 45 min), the three computer-based WM tasks were administered to each child individually in a random order. Within 10 days, the second session with groups of four to 10 children took place (about 90 min). First, to familiarize the children with the navigational design of the upcoming MHE, a training environment about different countries structured in the same way as the learning environment was administered to them. The children were allowed to practice with the training environment until they felt confident about using it. Afterwards, the real learning phase about biodiversity of fish began. To ensure that all children had sufficient prior knowledge about the subject matter and could adequately cope with the upcoming task demands, they were presented with a short introductory film about fish (about 5 min). This film invited the children to take on the role of a fish keeper in an aquarium and provided them with information about fish diversity based on the different perspectives presented in the MHE (e.g., different living environments). Subsequently, the children worked individually in the MHE for about 45 min by implementing the exploration tasks. Finally, after completing the learning phase, the children had to work on a posttest comprising the inferential questions and the scientific transfer questions (about 20 min).

Results

Descriptive statistics for the three navigational behaviors (perspective processing, content processing, irrelevant processing), the three WM tasks (spatial span, listening span, 2-

back), the exploration performance (exploration tasks), and the learning outcomes (inferential questions, scientific transfer questions) are presented in Table 2.

Table 2

Mean Scores (Standard Deviations) for the Three Navigational Behaviors (Perspective Processing, Content Processing, Irrelevant Processing), the Three WM Tasks (Spatial Span, Listening Span, 2-Back), the Exploration Performance (Exploration Tasks), and the Learning Outcomes (Inferential Questions and Scientific Transfer Questions)

Type of measure (unit/range)		*M* (*SD*) (*N* = 97)
Navigational behaviors	Perspective processing (in s)	936.65 (423.08)
	Content processing (in s)	620.20 (262.51)
	Irrelevant processing (in s)	988.07 (417.24)
Working memory measures	Spatial span (1-15)	8.50 (2.68)
	Listening span (1-9)	5.42 (1.81)
	2-back (percentage correct)	70.49 (18.38)
Exploration performance	Exploration tasks (percentage correct)	47.66 (16.10)
Learning outcomes	Inferential questions (percentage correct)	41.72 (19.82)
	Scientific transfer questions (percentage correct)	37.89 (32.97)

The Relation between WM Capacity, Navigation, and Performance

Table 3 presents correlational analyses for all three navigational behaviors, WM capacity, the exploration tasks, the inferential questions, and the scientific transfer questions. Next, we will present the results according to the respective hypotheses.

Hypotheses 1 and 2: WM capacity, performance, and navigation

With Hypothesis 1, we predicted that WM capacity would be positively related to exploration performance and learning outcomes in the MHE. As can be seen from Table 3, WM capacity was strongly related to performance on the exploration tasks ($r = .55$, $p < .001$), the inferential questions ($r = .52$, $p < .001$), and the scientific transfer questions ($r = .50$, $p < .001$), confirming Hypothesis 1.

Second, we hypothesized that WM capacity would be related to perspective processing and irrelevant processing but not to content processing. As expected, WM capacity was positively related to perspective processing (r = .38, p < .001) and negatively related to irrelevant processing (r = -.35, p = .001). Moreover, WM capacity was not related to content processing (r = .07, p = .49; see also Table 3), confirming Hypothesis 2.

Table 3

Intercorrelations Between the Three Navigational Behaviors, WM Capacity, the Exploration Tasks, the Inferential Questions, and the Scientific Transfer Questions

Type of measure	1	2	3	4	5	6	7
1) Perspective processing	-						
2) Content processing	-.24*	-					
3) Irrelevant processing	-.66**	-.31**	-				
4) WM capacity	.38**	.07	-.35**	-			
5) Exploration tasks	.60**	-.07	-.46**	.55**	-		
6) Inferential questions	.46**	-.11	-.33**	.52**	.71**	-	
7) Scientific transfer questions	.35**	.05	-.31**	.50**	.63**	.64**	-

Note. N = 97.
*p < .05. **p < .01.

Hypothesis 3: Navigational behaviors and performance

Hypothesis 3 predicted that perspective processing would be positively, irrelevant processing would be negatively, and content processing would not be associated with exploration performance and learning outcomes. To test this hypothesis, we computed three linear regression analyses with perspective processing, irrelevant processing, and content processing as independent variables and the exploration tasks, inferential questions, and scientific transfer questions as dependent variables. We z-standardized all variables beforehand to allow easier interpretation of the B-values. The linear regression analysis with the exploration tasks as the dependent variable, R^2 = .36, F(1, 95) = 17.71, p < .001, identified perspective processing as a significant predictor, B = 0.54, SE_B = 0.14; t(95) = 3.81, p < .001, but not irrelevant processing, B = -0.10, SE_B = 0.15; t(95) = -0.66, p = .513, or content processing, B = 0.03, SE_B = 0.11; t(95) = .26, p = .796. We found the same pattern of results when using the inferential questions as the dependent variable, R^2 =.22, F(1, 95) = 8.58, p < .001. Perspective processing significantly predicted learning performance, B = 0.41, SE_B = 0.16; t(95) = 2.63, p = .010, but irrelevant processing, B = -0.07, SE_B = 0.16; t(95) = -0.40, p = .688, and content processing, B = -0.03, SE_B = 0.13; t(95) = -0.25, p = .803, did not. Analogously, the linear regression analysis for the scientific transfer questions, R^2 = .14, F(1, 95) = 5.21, p = .002, identified perspective processing as a significant predictor, B = 0.36, SE_B = 0.16; t(95) = 2.16, p = .033, but not irrelevant processing, B = -0.04, SE_B = 0.17; t(95) = -0.24, p = .808, or content processing, B = 0.12, SE_B = 0.13; t(95) = .93, p = .354. In sum, these results partially confirmed Hypothesis 3. As expected, we found that perspective processing was positively associated and content processing was not associated with exploration performance and learning outcomes. However, we did not find irrelevant processing to be negatively associated with exploration performance and learning outcomes.

Hypothesis 4: The mediating role of perspective processing

Finally, we aimed to investigate whether the positive relation of WM capacity with exploration performance and learning outcomes might be explained by the use of perspective processing. To this end, we conducted mediation analyses as described by Hayes (2013). In total, three models with each of the three performance measures (exploration tasks, inferential questions, and scientific transfer questions) as dependent variables were tested.

In Model 1, we examined the relation between WM capacity and exploration tasks while controlling for perspective processing. Although the relation between WM capacity and exploration tasks did not disappear (B = 0.38, SE = 0.08, p < .001), confidence intervals produced by the bootstrapping analyses showed that the indirect effect through perspective processing was significant (CI 95% [0.09, 0.29]).

In Model 2, we examined the relation between WM capacity and the inferential questions while controlling for perspective processing. Again, the relation between WM capacity and the inferential questions did not disappear (B = 0.40, SE = 0.09, p < .001). Still, confidence intervals produced by the bootstrapping analyses showed that the indirect effect through perspective processing was significant (CI 95% [0.05, 0.24]).

Finally, in Model 3, we examined the relation between WM capacity and the scientific transfer questions while controlling for perspective processing. Herein, neither the relation between WM capacity and the scientific transfer questions disappeared (B = 0.43, SE = 0.09,

$p < .001$) nor the confidence intervals produced by the bootstrapping analyses indicated a significant indirect effect through perspective processing (CI 95% [-0.01, 0.17]).

Taken together, the navigational behavior of perspective processing did not completely mediate the relation between WM capacity and performance. Still, the indirect effects through perspective processing were significant for the exploration tasks and inferential questions. Thus, although WM capacity itself still had a strong independent influence on performance, perspective processing could at least explain part of this association, partially confirming Hypothesis 4.

Discussion

The present study investigated the interplay of WM capacity, navigational behaviors, and exploration performance and learning outcomes in an MHE. More specifically, we first aimed to replicate the positive association between WM capacity and hypermedia learning in a sample of elementary school children. In line with earlier studies (e.g., Pazzaglia et al., 2008), our results revealed that WM capacity was strongly associated with exploration performance (i.e., solving exploration tasks) and learning outcomes (i.e., answering inferential questions and scientific transfer questions). To conclude, the positive effect of high WM resources on hypermedia learning is generalizable to elementary school children working in MHEs.

WM Capacity and Navigational Behaviors

Moreover, we explored the relation of WM capacity and navigational behaviors in an MHE. In accordance with our hypothesis, we found that WM capacity was positively related to perspective processing, whereas it was negatively related to irrelevant processing. Moreover, WM capacity was not related to content processing. To conclude, children with high WM capacity engaged in perspective processing more than children with low WM capacity. Children with low WM capacity, instead, engaged in more irrelevant processing. Potentially, these children suffered from the “the seductive details effect” (cf. Sanchez & Wiley, 2006). Seductive details are highly interesting and entertaining contents that are however irrelevant for the current learning goal and can thus hamper learning. As our MHE contained a plethora of informative but concurrently seductive features (e.g., videos or animations), it posed a risk of distraction for children with low WM capacity or a small amount of executive control. These children may have found it difficult to resist the seductive information and thus engaged in irrelevant processing. Taken together, the executive control functions associated with WM, such as switching attention between different perspectives (i.e., perspective processing) or focusing attention while inhibiting irrelevant information (i.e., avoiding irrelevant processing), seem to play a crucial role in effectively navigating an MHE.

Navigational Behaviors and Performance

Furthermore, we focused on the relations between the different navigational behaviors and all performance measures (exploration tasks, inferential questions, scientific transfer questions). As expected, perspective processing positively predicted performance, whereas content processing was not related to performance. Thus, the selection of conceptual overview pages to relate various contents across different perspectives represents an effective navigational behavior when exploring MHEs. By contrast, the mere processing of content materials (although task-relevant) does not represent an effective navigational behavior. As theoretically assumed, content processing might not be sufficient for facing the challenges of an MHE. Other than expected, irrelevant processing did not significantly predict performance, although it was negatively correlated with performance when considered alone (see Table 3). It might be the case that its substantial negative correlation with perspective processing (r = -.66, p < .001), which emerged as a stronger predictor of performance, overrode the effects of irrelevant processing.

The Mediating Role of Perspective Processing

Finally, perspective processing was revealed to partially mediate the relation between WM capacity and performance on the exploration tasks and on the inferential questions. These mediation effects provide insights into the underlying processes that are responsible for the repeatedly found association between WM capacity and hypermedia learning (e.g., Pazzaglia et al., 2008). More precisely, the present results indicate that WM capacity leads to more effective navigation, namely perspective processing, which in turn leads to higher exploration and inferential performance. However, it should be noted that perspective processing could explain only part of the relation and did not even mediate the relation between WM capacity and performance on the scientific transfer questions at all. Thus, WM capacity still strongly influenced performance beyond this navigational behavior or even completely independent of it. This is not surprising as WM capacity is also assumed to be involved in activities (e.g., information processing) that cannot be directly mapped onto navigational processes but strongly influence learning and comprehension (Kyllonen & Christall, 1990). Due to the richness of information in hypermedia environments, information processing activities—such as processing large amounts of information, integrating different kinds of information, and keeping the results in mind during subsequent processing steps (cf. Ericsson & Kintsch, 1995)—are particularly challenging in these environments. Accordingly, learners with high WM resources might be—independent of their navigational processes—better able to cope with these information processing demands and thus display higher achievement in these learning settings than learners with low WM resources.

Limitations and Outlook

First, as the results of our study were based on correlational data, we cannot draw causal inferences concerning the relations between WM capacity, navigational behaviors, and performance. Therefore, we cannot take the results of the mediation analyses as evidence of causal effects but should interpret them cautiously. It might be possible that the perceived relations were confounded by unobserved variables that were not included in the analysis (e.g., intelligence, socioeconomic status). Thus, the results of the mediation analyses can be taken only as an indication of how the effect of WM capacity on performance might be explained.

Second, our inferential questions had a relatively low reliability. This might be explained by the fact that the inferential questions required the children not only to make inferences but also to reactivate their acquired fish knowledge. That is, contrary to tests that deal with a homogenous construct (i.e., personality or intelligence tests), knowledge tests comprise various multifaceted items to capture different and potentially independent aspects of a knowledge domain. For instance, a child may have understood the differences between river fish and tropical reef fish, thereby answering a corresponding question correctly. By contrast, he or she may have failed to understand how the different ivories of the breams are associated with their eating habits, thereby not receiving a point for a corresponding question. Such a pattern of answers may result in lower internal consistency, which however cannot be taken for granted as a valid indicator of the quality of the measurement. Despite this relatively low reliability, our findings still achieved significance. It is even possible that a higher reliability would have resulted in larger effects.

Finally, the present study focused on log files to shed light on the processes that underlie hypermedia exploration and learning. By conducting complex log file analyses, it was possible not only to determine the children’s on- and off-task navigational processing but also to reveal different navigational behaviors that were highly predictive of hypermedia learning. Still, log files are limited as they cannot provide information about conscious intentions while processing. Future studies could thus additionally include other process measures (e.g., think-aloud protocols, eye-tracking), which might provide further insight into learners' processing (e.g., concerning their awareness of navigational behaviors or reasons for their navigational decisions).

Conclusion

Considering the present findings, WM capacity appears to represent an important learning prerequisite when exploring MHEs. More precisely, WM capacity not only seems to impact exploration and learning but also seems to be strongly associated with effective navigation in these environments, namely with perspective processing. Thus, in order to benefit from MHEs, it is not sufficient to engage in task-relevant processing of learning materials (content processing), but it is particularly important to select different conceptual overview pages (perspective processing). Unfortunately, however, only children with high WM capacity seem to be able to apply this effective navigational behavior. Thus, MHEs should be implemented in a classroom only if the group of students consists of advanced learners, namely of students with high WM capacities, or if the students are provided with appropriate navigational training. However, whether students with low WM resources can actually adapt their respective navigational behaviors or whether learning opportunities should instead be adapted to students' capabilities remains to be seen. In line with the latter proposition, for instance, Cowan (2013) claimed that "For learning and education, it is important to take into account the basic principles of cognitive development and cognitive psychology, adjusting the materials to the working memory capabilities of the learner" (p. 22). According to this reasoning, MHEs seem to be an effective implementation in the educational context at least for learners with high WM capacity.

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5

General Discussion

5 General Discussion

The present dissertation focused on the interplay of giftedness, working memory (WM) capacity, and hypermedia learning. In particular, it was examined whether WM capacity represents an essential characteristic of teacher-nominated gifted children that might even outperform the influential characteristic of fluid intelligence for predicting whether a child is nominated as gifted by teachers or not (Study 1). Moreover, based on the idea of *aptitude-treatment interaction* (ATI; Cronbach & Snow, 1977), it was explored whether learning offers that take advantage of high WM resources, such as hypermedia environments, are actually more beneficial for children with respective cognitive resources than learning offers that do not require high WM resources, such as more linearly structured materials (Study 2). Finally, the present dissertation dwelled on the underlying processes that might explain the positive association of WM capacity and learning in the context of hypermedia instruction, namely navigational processes (Study 3). In the following, the central results of the three conducted studies will be summarized and interpreted (5.1). Then, strengths and limitations of the present dissertation will be discussed (5.2). The third part of the General Discussion deals with implications for future research and educational practice (5.3). Finally, the General Discussion will conclude with a short summary of the most important findings of the present dissertation (5.4).

5.1 General Findings of the Conducted Studies

5.1.1 Study 1: The role of working memory capacity in teacher-nominated gifted children

Considerable scientific attention has been directed to the identification of gifted children via teachers' nominations (e.g., Endepohls-Ulpe & Ruf, 2005; Hernández-Torrano, Prieto, Ferrándiz, Bermejo, & Sáinz, 2013; Kim, Shim, & Hull, 2009; Siegle, Moore, Mann, & Wilson, 2010; Siegle, & Powell, 2004). Previous research in this context has revealed that teachers' nominations are influenced by a variety of student characteristics including demographic, cognitive, and non-cognitive characteristics (e.g., Endepohls-Ulpe & Ruf, 2005; Hernández-Torrano et al., 2013; Kim et al., 2009). However, one important cognitive characteristic has received less attention so far, namely WM capacity (e.g., Baddeley, 2002). Thus, in order to extent previous research in this context, Study 1 focused on the role of WM capacity for characterizing teacher-nominated gifted children. More specifically, it was explored whether teacher-nominated gifted children have a higher WM capacity than other children. Additionally, the children were compared with regard to their STM capacity to rule out the possibility that it is the simple storage buffer instead of the executive control functions that discriminates between teacher-nominated gifted children and other children (cf. Swanson, 2006). Finally, the role of WM capacity was compared with the role of fluid intelligence in characterizing these children. To this end, 42 teacher-nominated gifted fourth-graders were compared to 39 non-nominated fourth-graders in terms of their WM capacity, their STM capacity, and their fluid intelligence.

As hypothesized, the results of Study 1 indicated that teacher-nominated gifted children had a significantly higher WM capacity than non-nominated children. On the contrary, but also as expected, STM capacity revealed to be similar in both groups indicating that particularly the executive control functions associated with WM capacity characterize teacher-nominated gifted children and not the simple storage function. These results are in line with previous studies that investigated the role of WM capacity in gifted children who had been identified by an achievement or intelligence test (e.g., Swanson, 2006; Vock, 2005). Furthermore, WM capacity revealed to be equally important as fluid intelligence in characterizing teacher-nominated gifted children. More precisely, WM capacity and fluid intelligence together best discriminated between teacher-nominated gifted children and non-nominated children with both variables possessing unique validity in logistic regression analyses. WM capacity even outperformed fluid intelligence descriptively with regard to its b-coefficient and odds ratio. This finding is consistent with Sternberg's componential theory of intellectual giftedness (1981), which stresses the importance of different cognitive processes that have to complement each other for effective cognitive functioning, namely high-level processes, such as fluid intelligence, and low-level processes, such as WM capacity.

In sum, Study 1 revealed WM capacity to be a crucial characteristic of teacher-nominated gifted children, even beyond intelligence. Considering similar findings with intellectually gifted children (e.g., Swanson, 2006), it seems to be justified to emphasize the construct of WM more strongly in the field of giftedness. Moreover, from an educational perspective, learning settings that demand high WM resources and concurrently better stimulate active learning might be more beneficial for these learners than traditional, less activating learning materials (see Study 2).

5.1.2 Study 2: The role of working memory capacity in multiperspective hypermedia environments

Based on the extensive literature supporting ATI effects (e.g., Kieft, Rijlaarsdam, & van den Bergh, 2008; Münzer, 2012; Seufert, Schütze, & Brünken, 2009; Skuballa, Schwonke, & Renkl, 2012; Sternberg, Grigorenko, Ferrari, & Clinkenbeard, 1996), it is important to adapt learning instructions to learners' particular learning prerequisites in order to provide appropriate learning offers. According to the results of Study 1, teacher-nominated gifted children are characterized by high WM resources. Thus, appropriate learning offers for (teacher-nominated) gifted children should take advantage of these resources, namely of the learners' high WM capacity. In this vein, Study 2 focused on the suitability of a multiperspective hypermedia environment (i.e., a hypermedia environment that requires learners to simultaneously consider multiple perspectives of a topic; cf. Lima, Koehler, & Spiro, 2002), which does not only require a high degree of WM resources but also represents an innovative instructional approach. Compared to more traditional, linearly structured materials, multiperspective hypermedia environments have been suggested to better support dealing with complex task demands and to better stimulate high-level thinking (Jacobson & Spiro, 1995; Salmerón & García, 2012; Spiro & Jehng, 1990). Therefore, Study 2 addressed the research question as to whether children with high WM capacity benefit more from a multiperspective hypermedia environment than from a linear learning environment for complex task demands (i.e., complex exploration tasks) and high-level thinking (i.e., multiperspective reasoning), but not for simple task demands (i.e., simple exploration tasks). To this end, 186 fourth-graders either worked through a multiperspective hypermedia environment (N = 97) or through a linear learning environment (N = 89) by dealing with the exploration tasks as well as with the multiperspective reasoning task.

Surprisingly, the results of Study 2 revealed that for the simple exploration tasks children with high WM capacity benefitted more from the multiperspective hypermedia environment than from the linear learning environment. Thus, other than expected, multiperspective hypermedia environments can also be more beneficial than linear environments for achieving simple learning goals. One explanation might be that the linear learning environment was not interesting enough to stimulate high WM children to engage in the exploration of these simple tasks so that, after all, the multiperspective hypermedia environment revealed to be more beneficial. Children with low WM capacity, by contrast, did not benefit more from the multiperspective hypermedia environment than from the linear environment for the simple exploration tasks. Moreover, also contrary to expectations, for the complex exploration tasks the linear learning environment demonstrated to be much more beneficial for all children, independent of their WM capacity. The complex exploration tasks demanded from the children to integrate and relate different information in order to answer a respective question. Whereas in the linear environment all necessary information was presented on the same page, children in the multiperspective hypermedia environment were required to collect and integrate the information from different locations in the environment. This fragmentation of information might have reduced coherence between to-be-integrated information and consequently hampered performance (Shapiro & Niederhauser, 2004; van Dijk & Kintsch, 1983). Thus, although Salmerón and García (2012) proposed that the network-like structure of a hypermedia environment supports the mental integration of related ideas that are separately located in the environment, this might not be true, even not for learners with high WM capacity, if the integration demands are too complex. Finally, the results of Study 2 demonstrated that children with high WM resources significantly benefitted more from the multiperspective hypermedia environment than from the linear environment in terms of their later engagement in multiperspective reasoning, that is, drawing elaborated inferences based on the simultaneous consideration of multiple perspectives (cf. Fitzgerald, Wilson, Semrau, 1997; Zydney, 2010). Thus, in line with theoretical assumptions and with previous research (cf. Spiro & Jehng, 1990), the multiperspective hypermedia environment was better able to stimulate high-level thinking (i.e., multiperspective reasoning) in children with high WM capacity than the linear environment. Children with low WM capacity, by contrast, showed comparably low multiperspective reasoning performance in both learning conditions (i.e., multiperspective hypermedia and linear). This is not surprising as, on the one hand, the multiperspective hypermedia environment might have been cognitively overwhelming for these children and, on the other hand, the linear environment was not suitable to stimulate multiperspective reasoning.

In sum, Study 2 demonstrated that multiperspective hypermedia environments can be more stimulating for children high in WM capacity than linear environments (i.e., for simple exploration tasks and multiperspective reasoning) but can also be cognitively overwhelming when the task demands are too complex (i.e., for complex exploration tasks). Importantly, although the integration of information in the multiperspective hypermedia environment to solve the complex exploration tasks might have even overchallenged children with high WM capacity, the multiperspective hypermedia environment still better stimulated their later engagement in multiperspective reasoning than the linear environment. Nevertheless, it might be valuable to disentangle the unexpected results in future studies in order to adapt the learning environment or the learning tasks to the learners more adequately (see also 5.2.3 and 5.3.1). Children with low WM capacity, by contrast, never seemed to benefit more from the multiperspective hypermedia environment than from the linear learning environment. Thus, learning offers, such as multiperspective hypermedia environments, are differentially effective in two ways. On the one hand, they are only beneficial for some specific type of learning tasks (i.e., herein for simple exploration tasks and multiperspective reasoning), and, on the other hand, they are only beneficial for certain learners (i.e., herein for learners with high WM resources). Although the differential effectiveness of the multiperspective hypermedia environment for the learning tasks was reverse to the present hypotheses – beneficial for simple but not for complex exploration tasks –, its differential effectiveness for different learners (i.e., high or low WM capacity) still appeared to be salient. This latter aspect emphasizes once more the importance of ATI (Cronbach & Snow, 1977), namely the importance of appropriately matching learning offers to learners' prerequisites.

5.1.3 Study 3: The interplay of working memory capacity, navigational behaviors, and performance in multiperspective hypermedia environments

Based on the findings concerning the positive relation between WM capacity and performance in multiperspective hypermedia environments (Study 2), the present dissertation additionally included an investigation of the underlying processes, namely navigational processes, that might be responsible for the respective relation. Navigational behaviors have been demonstrated to strongly influence comprehension and learning when dealing with hypermedia environments (e.g., Lawless, Brown, Mills, & Mayall, 2003; Naumann, Richter, Christmann, & Groeben, 2008). However, navigational behaviors that might be particularly effective when dealing with multiperspective hypermedia environments have received less attention so far. Moreover, the impact of WM capacity for effective navigation has not yet been empirically investigated, although, on a theoretical level, it is likely to assume that WM is involved in a variety of navigational processes (e.g., McDonald & Stevenson, 1996). Therefore, Study 3 explored the association of WM capacity, navigational behaviors, and performance in a multiperspective hypermedia environment. For this purpose, the log files of the 97 fourth-graders who experienced the multiperspective hypermedia environment in Study 2 were analyzed according to three types of navigational behaviors: (1) perspective processing (i.e., selection of conceptual overview pages that display the linking structure of the content nodes within different perspectives), (2) content processing (i.e., selection of specific content pages without taking the linking structure of the content nodes into account), and (3) irrelevant processing (i.e., navigational behaviors that do not address a given learning task). Additionally, measures of the children's WM capacity as well as of their exploration performance (exploration tasks; see Study 2) and learning outcomes (inferential questions: combining fish-facts and drawing conclusions; scientific transfer questions: transferring structural fish knowledge to a novel topic) were related to the navigational behaviors.

As expected, the results of Study 3 indicated that WM capacity was strongly related to the navigational behavior of perspective processing. Perspective processing, in turn, turned out to be a meaningful predictor of exploration performance and learning outcomes. Moreover, WM capacity was negatively related to irrelevant processing. Unexpectedly, however, irrelevant processing did not negatively predict exploration performance and learning outcomes when considered simultaneously with perspective processing. Probably, the substantial negative correlation between irrelevant processing and perspective processing overrode the effect of irrelevant processing. Finally, and in line with theoretical assumptions, content processing was neither related to WM capacity nor to exploration performance and learning outcomes. Thus, applying the navigational behavior of content processing might not be sufficient in multiperspective hypermedia environments as they are not designed to primarily convey isolated factual knowledge (e.g., Jacobson & Spiro, 1995). Rather, they aim to convey broad conceptual knowledge about a topic domain, which challenges navigational behaviors that take the linking structure of the contents into account (i.e., perspective processing). Taken together, children with high WM capacity appeared to engage more in perspective processing and less in irrelevant processing than children with low WM capacity. The latter might result from the fact that children low in WM capacity may not be able to resist seductive contents, that is, highly interesting and entertaining contents, which are however irrelevant for the current learning goal (cf. Sanchez & Wiley, 2006). Furthermore, mediation analyses demonstrated that perspective processing partially mediated the association between WM capacity and exploration tasks as well as between WM capacity and inferential questions. This finding indicates that at least to a certain degree perspective processing is responsible for the repeatedly found association between WM capacity and performance (e.g., Pazzaglia, Toso, & Cacciamani, 2008). However, WM capacity still influenced performance beyond perspective processing. This is not surprising as WM is also involved in further cognitive activities that are important for comprehension and learning but that are not directly associated with navigational processes, such as, for instance, information processing activities (Kyllonen & Christal, 1990).

In sum, Study 3 further stressed the importance of WM capacity when dealing with multiperspective hypermedia environments. Specifically, results of the study showed that children with high WM capacity engaged more in perspective processing than children with low WM capacity. Perspective processing, in turn was associated with higher exploration performance and learning outcomes. Children with low WM capacity, by contrast, were rather characterized by the unfavorable navigational behavior of irrelevant processing. Finally, the degree to which students engaged in content processing did not distinguish between high and low WM students (or successful and unsuccessful students) in the context of multiperspective hypermedia learning. To conclude, multiperspective hypermedia environments should mainly be applied to children high in WM capacity or to children (with lower WM capacity) who have been provided with an appropriate navigational training beforehand. However, whether such a navigational training actually makes these students benefit more from respective learning offers remains to be discussed (see also 5.3.1).

5.2 Strengths and Limitations of the Present Dissertation

Before dwelling on the implications that can be derived from the central findings of the three empirical studies, some strengths and limitations of the present dissertation will be discussed. Specifically, four main issues will be examined including the methodological approach applied, the chosen sample, the newly developed materials, and the log file analyses. All four issues represent main strengths of the present dissertation but simultaneously imply a few limitations that should not be overlooked.

5.2.1 Methodological approach

It can be considered as one of the main strengths of the present dissertation that the three studies theoretically and empirically built upon each other. More precisely, the research questions of Study 2 and 3 were not only based on theoretical reasoning but also arose from the empirical findings of the preceding studies. For instance, Study 2 (e.g., the learning environment) was designed based on the results of Study 1 (e.g., the particular learner prerequisites). Moreover, Study 3 helped to further disentangle the findings of Study 2 by taking navigational processes into account.

No less important is that the present dissertation was aimed at combining different fields of research, that is, the field of giftedness, the field of cognitive psychology, and the field of hypermedia instruction, and consequently, attempted to combine different methodological approaches. Specifically, whereas research on giftedness is more closely associated with field studies (e.g., Neber, 2004; Rost, 1993; Wai, Lubinski, Benbow, & Steiger, 2010), research on cognitive psychology and hypermedia instruction is more closely associated with controlled experimental designs (e.g., Jacobson & Spiro, 1995; Niederhauser, Reynolds, Salmen, & Skolmoski, 2000; Lee & Tedder, 2003). Accordingly, on the one hand, the studies of the present dissertation were conducted in the field (i.e., giftedness academy, schools), thereby ensuring a realistic study setting. In this respect, for instance, it is to appreciate that the teacher-nominated gifted group in Study 1 was recruited from an existing enrichment academy, the Hector Children Academy. This increases the external validity of the present results. On the other hand, the studies of the present dissertation included (quasi)experimental aspects such as a control group design, the randomized assignment to the learning conditions, and the development of two comparable learning environments that only differed in their presentation structure (hypermedia vs. linear). Apart from that, and based on the materials used in the field of cognitive psychology and hypermedia instruction, the materials of the present dissertation consisted of computer-based WM measures as well as tablet-based learning applications. Note that the majority of field studies, by contrast, merely comprises questionnaires (e.g., Rost, 1993; Trautwein, Lüdtke, Marsh, Köller, & Baumert, 2006; Wai et al., 2010).

At the same time, however, this combination of different methodological approaches comes with some drawbacks. First, compared to field studies, the present dissertation did not include equally large sample sizes, a multilevel model, or a longitudinal design. As field studies mainly comprise questionnaires (e.g., Rost, 1993; Wai et al., 2010), it is therein easier to fulfill the demands for huge sample sizes, which allow to take the multilevel nature of the data into account (Raudenbush & Bryk, 2002). This aspect can also be applied to longitudinal designs. However, as the materials of the present dissertation were much more complex and difficult to apply than questionnaires, a corresponding longitudinal investigation in a very large sample would have been too costly. Consequently, the multilevel structure of the data could not be taken into account for the statistical analyses conducted within the present dissertation (see also 5.3.1). Moreover, as no longitudinal design was applied, the analyses within each single study were based on cross-sectional data so that no strong causal inferences concerning the relations among the variables can be drawn. With regard to Study 1, for instance, it cannot be ruled out that teachers' giftedness nominations and consequently children's participation in a promotion program influenced children's WM capacity (e.g., due to training effects of the intervention) rather than children's WM capacity had affected teachers' giftedness nominations. Moreover, with regard to Study 3, the results of the mediation analyses including WM capacity, perspective processing, and performance cannot be considered as a causal proof. Instead, and in line with other studies conducting similar analyses on a correlational basis (e.g., Trautwein et al., 2006), the findings can only be considered as an indication of how a specific effect might be explained. Potential statistical analyses that might verify the present results will be further discussed in Section 5.3.1.

Furthermore, compared to laboratory studies, which also investigate the interplay of cognitive processes and learning (e.g., Lee & Tedder, 2003), the internal validity of the present studies is limited to some extent, as an investigation of this issue in the field is always prone to disruptions. For example, referring to an existing teacher-nominated gifted sample in Study 1 instead of conducting a predefined and standardized selection of respective children (i.e., asking a small sample of teachers to nominate some children according to specific criteria), involves a certain risk of analyzing idiosyncrasies. Moreover, for the purpose of organizational and instructional reasons in Study 2, all children of the same class explored the same learning environment (i.e., either the multiperspective hypermedia environment or the linear environment) so that the randomization process was limited (i.e., no randomization of individual students but of fixed classes).

Taken together, the combination of different research traditions can be quite valuable as it allows thinking outside the box. Nevertheless, it is concurrently associated with several challenges such as, for instance, investigating a large sample size in the field with costly materials (i.e., tablet-based learning environments). These challenges might be worth to be addressed prospectively.

5.2.2 Sample

Another aspect that has both positive and negative implications, is that all research questions were addressed in the same target group, namely fourth-graders. This target group was chosen because teachers' nominations of gifted students have been reported to be more reliable for elementary school children than for secondary school children (Endepohls-Ulpe & Ruf, 2005). The fact is that elementary school teachers interact with their students more frequently, namely in different subjects, so that they can take more characteristics of the students into account and are thus assumed to be better able to judge a student's giftedness than secondary school teachers (Endepohls-Ulpe & Ruf, 2005; McBee, 2006). Therefore, the present dissertation focused on elementary school children in Study 1. For the purpose of comparability, Study 2 (or 3, respectively) was conducted with fourth-graders as well.

Another reason for why this target group was of particular interest in study 2 (or 3) is that innovative instructional environments such as hypermedia environments are increasingly advocated in the educational context (e.g., Falloon, 2013). Especially since the increasing interest in tablet computers, which seem to be more adapted to the skills of younger children than traditional computers (Lane & Ziviani, 2010), an application of such innovative environments can also be found among elementary school children. Therefore, it is valuable to focus on how these environments benefit this target group.

Apart from reasons in favor of this target group, however, the same is also associated with some limitations. That is to say, cognitive variables, such as WM capacity, are not fully developed in young learners, so that the findings of the present dissertation concerning the relation of WM capacity with other variables might not be generalizable to older age groups. It has been shown that children's memory span significantly increases during early school years which most likely results from an improvement of the WM system (Fry & Hale, 2000; Gathercole & Baddeley, 1993). In this vein, for example, Gathercole, Pickering, Ambridge, and Wearing (2004) longitudinally investigated children's increase in WM capacity from age four to age 15. They demonstrated that the storing functions as well as the executive control functions of WM remarkably expanded throughout the years. In line with this reasoning, it is likely that older students show a more elaborated approach when dealing with multiperspective hypermedia environments as well as a more effective selection of navigational behaviors. Thus, investigations with older students might be valuable (see 5.3.1).

5.2.3 Developed materials

One major strength but concurrently a limitation of the present dissertation is that nearly all study materials were newly developed (i.e., WM measures, learning environments, performance measures). On the one hand, the materials were adjusted to the goals and the sample of the studies in order to optimally serve their purpose. On the other hand, however, the materials had never been validated beforehand so that their psychometric qualities were unknown and rather limited.

Starting with the three WM measures (listening span, spatial span, 2-back), whose selection was based on theoretical and practical reasons (i.e., different content materials, different research traditions (see 1.4), suitability for fourth-graders, commonly used WM measures), it is to appreciate that all measures have been adopted from existing WM instruments and adjusted to the circumstances of the current studies. More precisely, two of the measures (spatial span, listening span) were adapted from Vock’s (2005) WM battery but were entirely conducted computer-based (and not with paper-pencil), which guaranteed a more standardized assessment. The 2-back task, as a typical WM measure in neuroscience (e.g., Jaeggi, Buschkuehl, Perrig, & Meier, 2010), was correspondingly adapted to the other two tasks. However, although the selection of the tasks was theoretically-driven, these three WM measures had not been tested and validated in a large sample before. Therefore, it is not clear to what extent these measures represented valid WM measures. Moreover, as no norm sample existed, the interpretation of the absolute WM scores was not possible. Nevertheless, the WM measures used were able to differentiate between the participants of the present studies so that at least the relative WM scores were interpretable and could be used to answer the research questions. However, it would be valuable to further validate these measures.

Moreover, within the scope of Study 2 (or 3, respectively), the elaborate multiperspective hypermedia environment about ‘biodiversity of fish’ was developed. To implement this learning environment, a touch screen interface (i.e., tablet) was used to better adapt the learning environment to the skills of the young children who are supposed to still have difficulties with mouse-interactions of a traditional computer (Lane & Ziviani, 2010; Lu & Frye, 1992). Most importantly, the structure of the learning environment and the presentation of the content were designed to stimulate autonomous and active exploration of the contents. Such active exploration has been suggested to lead to deeper elaboration of the learning materials, to more networked knowledge, and to better knowledge transfer (Mayer, 2004; Shute & Glaser, 1990). Note that this design was simultaneously assumed to require a high degree of executive control and information processing abilities from the user (i.e., high WM capacities). Through cooperation with biology scientists specialized in fish and computer scientists specialized in the development of iPad-based learning environments, the validity of the content materials as well as the professionalism of the digital learning offer were additionally ensured. These efforts notwithstanding, the multiperspective hypermedia environment did not reveal to be unconditionally beneficial for children with high WM capacity. More precisely, children seemed to be unable to cope with the demands of the multiperspective hypermedia environment when dealing with the complex exploration tasks. Thus, either the design of the multiperspective hypermedia environment was not supportive enough for this young age group or the kind of questions did not fit to the respective design. An inclusion of further tasks as well as slight design changes concerning the learning environment might help to better understand the dynamics at play (see 5.3.1).

Finally, the performance measures (i.e., exploration tasks, inferential questions, scientific transfer questions or multiperspective reasoning task, respectively) were specifically developed for the present dissertation. More precisely, the content of these measures was adapted to the learning environment about fish. Thus, on the one hand, the materials were adjusted to the goals and the circumstances of the current studies. On the other hand, however, the reliability as well as the validity of these measures could be questioned. Accordingly, the results of the studies revealed that the reliability of some of the measures was quite low, although still acceptable. This indicates that the psychometric qualities of the measures were not always optimal which might have biased some of the present results. Note, however, the present measures were shown to be sensitive to the experimental manipulation. Moreover, whether the measures actually assessed the construct, which was intended to be assessed, cannot be guaranteed as no validation of these measures had been conducted beforehand. Thus, a further construct validation of these measures would be desirable with respect to future studies.

To conclude, all materials have been developed to the best of knowledge, that is, according to the goals and the samples of the studies. Given that the psychometric qualities of the present measures are yet to be assessed, one should be careful when trying to generalize conclusions from the present results.

5.2.4 Log file analyses

Study 3 of the present dissertation comprised complex log file analyses to investigate the processes that underlie hypermedia exploration and learning in more detail. Log files provide additional information about the learning process by recording the learners` navigational paths, that is, learners' navigational choices as well as the time they spent on certain contents (Barab, Bowdish, & Lawless, 1997). In this sense, log files are better suited to capture underlying learning processes than traditional measures such as recall tasks, which are mostly assessed after task completion (Young & McNeese, 1995). Barab, Bowdish, Young, and Owen (1996) emphasized the predictive validity of log files. Specifically, they demonstrated that log files predicted with 80% accuracy whether learners pursued a specific learning goal or whether they merely browsed aimlessly. Accordingly, the log file analyses conducted within the present dissertation also allowed determining whether children addressed a specific task demand (i.e., exploration tasks with perspective processing or content processing) or whether they browsed aimlessly (irrelevant processing). Additionally, navigational behaviors based on the log files turned out to significantly predict exploration performance and learning outcomes of the students. Nevertheless, log files cannot provide explicit information about conscious intentions while processing, such as the learners' awareness of their navigational strategies or reasons for navigational decisions. Therefore, an additional inclusion of further process measures, such as think-aloud protocols or eye-tracking, might be worthwhile. Respective process measures will be discussed in more detail in Section 5.3.1.

5.3 General Implications and Future Directions

The empirical findings of the three studies conducted within the present dissertation comprise several implications. On the one hand, they give rise to questions that might be addressed in future research (5.3.1). On the other hand, useful implications for educational practice can be inferred (5.3.2). Hereinafter, the present dissertation will first dwell on implications for future research and will secondly discuss practical implications.

5.3.1 Implications for future research

In the following, implications for future research that are related to three different issues will be deduced. First, the present dissertation extended previous research on characteristics of teacher-nominated gifted children. The present findings give rise to new research questions that should be addressed in upcoming research (see 'Exploring teachers' giftedness nominations'). Second, the present dissertation demonstrated under which conditions multiperspective hypermedia environments seem to be beneficial and under which conditions they might even be harmful. The following section will address issues concerning future directions for further exploring and validating the respective findings (see 'Exploring the effects of hypermedia instruction'). Third, it will be discussed to what extent alternative methodological approaches can be prospectively applied to expand and clarify the results of the present dissertation (see 'Exploring alternative methodological approaches').

Exploring teachers' giftedness nominations

The present dissertation demonstrated that WM capacity represents a crucial characteristic of teacher-nominated gifted children, which seems to be as prevalent as fluid intelligence. However, it is questionable whether such an elementary cognitive variable can be actually perceived by teachers. Instead, it is more reasonable that other, more visible characteristics that are strongly related to WM and concurrently meaningful in the educational context are considered such as, for instance, verbal abilities and reading comprehension (Leong, Hau, Tse, & Loh, 2007; Seigneuric & Ehrlich, 2005), language processing (Shah & Miyake, 1996), or mathematical skills (Alloway & Passolunghi, 2011; Simmons, Willis, & Adams, 2012). Furthermore, these learner characteristics also influence the achievement (i.e., grades) of a student (e.g., Alloway & Alloway, 2010), which, in turn, has already been demonstrated to strongly impact teachers' giftedness selections (e.g., Hanses & Rost, 1998; Hany, 1991; Rost & Hanses, 1997). Thus, it is likely that these favorable learner characteristics and/or the achievement level of a student might shape a teacher's perception of a child and might consequently influence teachers' giftedness judgments rather than the cognitive variable of WM itself. Therefore, it would be interesting to investigate the interplay of WM with more directly observable learner characteristics as well as with achievement in the field of giftedness nominations. For instance, mediation analyses, which examine whether more observable learner characteristics and/or the students' achievement mediate the link between WM capacity and teachers' decisions about giftedness, could provide further insight into this intertwining. Importantly, in order to appropriately investigate whether respective variables actually influence teachers' nominations a longitudinal design is necessary. How such a study design would have to be precisely operationalized will be further explored in the section 'Exploring alternative methodological approaches'.

Various studies in the context of giftedness nominations investigated individual students' characteristics that might influence teachers' giftedness judgments, such as gender, achievement motivation, or several cognitive characteristics (e.g., Hernández-Torrano et al., 2013; Endepohls-Ulpe & Ruf, 2005; Moon & Brighton, 2008). In line with this, the present dissertation also focused on an individual, but so far unattended learner characteristic, namely WM capacity. However, less attention has yet been devoted to contextual influences, although these have been shown to play an important role in the educational context (Kornmann, 2005; Lüdtke, Köller, Marsh, & Trautwein, 2005; Rjosk et al., 2014). For instance, a common composition or context effect is the big-fish-little-pond effect (BFLPE; Lüdtke et al., 2005). Specifically, the BFLPE refers to the effect that a student's academic self-concept depends on the class mean ability, with the student perceiving his or her self-concept to be lower when the class mean ability is higher (Lüdtke et al., 2005; Nagengast & Marsh, 2012; Parker, Marsh, Lüdtke, & Trautwein, 2013; Trautwein et al., 2006). Importantly, it has been shown that not only students but also teachers are influenced by the class context (cf. Lüdtke et al., 2005). That is to say, teachers are known for using a social reference standard when evaluating the ability or achievement of a student, namely by comparing one student with other students. In this sense, there is first empirical evidence that teachers also use a social reference standard to judge a student's giftedness (Anastasiow, 1964). In fact, Anastasiow (1964) demonstrated that the anchor for teachers' giftedness judgments equals the class mean ability. Thus, whether the same student is nominated as gifted or not depends on the class performance level, which a teacher considers to be the grade level standard. Conclusively, as teachers' giftedness judgments might be influenced by the class context, an inclusion of the class level perspective may yield further insight into the dynamics at play within teachers' giftedness nominations. More precisely, future studies should additionally take class level perspectives into account to disentangle the interplay of individual characteristics and contextual influences on teachers' giftedness nominations. Potential statistical analyses that appropriately address this kind of research question will be discussed in the section 'Exploring alternative methodological approaches'.

Beyond the issue of what might affect teachers' giftedness judgments, it is also worth considering how teachers' giftedness judgments influence a child's self-perceptions and abilities. Results of the present dissertation have indicated that teacher-nominated gifted students had a higher WM capacity and also a higher fluid intelligence than students who had not been nominated as gifted. However, to what extent the giftedness nomination itself (or the subsequent attendance of enrichment courses) might have influenced these abilities is not clear. In general, teacher expectations have been shown to be positively related to student's self-perceived academic competence (Cole, 1991) and to their long-term achievement (i.e., Pygmalion effect; Rosenthal, 2010). Therefore, it is likely to assume that teachers' giftedness judgments might also positively influence students' self-perceptions as well as their achievement and abilities. In this vein, for instance, Neber (2004) reported that students who had been nominated by their teachers for a giftedness promotion program had very high beliefs about their ability. However, it has, to the best of my knowledge, not yet been systematically investigated whether such a high self-perception of gifted students actually results from the giftedness nomination itself. Importantly, though, Neber (2004) critically remarked that many of the students overestimated their actual ability. Thus, whether a giftedness nomination only influences a student's self-perception or also his or her ability level is worth investigating as well. Therefore, in future studies it might be interesting to investigate the impact of the giftedness nomination on a student's shift in his or her self-perceptions and abilities as compared to students not having been nominated as gifted. Specifically, by comparing students who exhibit similar preconditions (i.e., concerning their WM capacity, their motivation, their self-concept, etc.) but of whom only half is nominated as gifted, would reveal to what extent the giftedness nomination itself affects students' self-perceptions and abilities (e.g., their WM capacity).

Exploring the effects of hypermedia instruction

The present dissertation indicated that WM capacity represents an important learning prerequisite in the context of hypermedia learning. Specifically, learners with high WM capacity benefitted more from a multiperspective hypermedia environment in terms of navigation and learning than learners with low WM capacity. Considering previous research in the field of hypermedia learning, the most influential learner characteristic so far seems to be prior knowledge (e.g., Carmel, Crawford, & Chen, 1992; Chen, Fan, & Macredie, 2006; Jacobson, Maouri, Mishra, & Kolar, 1996; Lawless & Kulikowich, 1996; Salmerón, Cañas, Kintsch, & Fajardo, 2005; Scheiter & Gerjets, 2007). For instance, learners with high prior knowledge show more effective navigational behaviors than learners with low prior knowledge (e.g., Carmel et al., 1992; Lawless et al., 2003). More precisely, high prior knowledge students seem to be more efficient at distinguishing between relevant and irrelevant information and seem to switch back and forth between related information nodes more often than low prior knowledge students (Lawless et al., 2003). In the present dissertation, children's prior knowledge was intentionally kept constant to avoid a confounding effect of prior knowledge with the variable of interest, namely WM capacity. To this end, a topic that was assumed to be relatively unexplored among this age group was chosen (i.e., biodiversity of fish). Moreover, all children were provided with the same basic topic information relevant for the learning environment (i.e., introductory film about fish). However, in order to estimate the importance of WM capacity as compared to prior knowledge for dealing with hypermedia environments, it might be interesting to explore the interaction between both variables. As WM capacity also revealed to strongly influence navigation in hypermedia environments, it might be that high WM capacity can somehow compensate for less prior knowledge or vice versa so that it is not mandatory for a learner to exhibit both preconditions (i.e., compensation effect). On the other hand, it might also be possible that high WM capacity even contributes to high prior knowledge implying that both preconditions have to be fulfilled in order to benefit most from hypermedia environments (i.e., additional effect). Future research should thus delve into the interplay of WM capacity and prior knowledge in the context of hypermedia learning. For instance, the influence of WM capacity on hypermedia learning could be compared between experts and novices concerning a certain topic. Specifically, with regard to the fish-topic used in the current dissertation, marine biology students could be compared to other students (i.e., students of mathematics or languages) with regard to their exploration performance and learning outcomes when dealing with the multiperspective hypermedia environment about fish-biodiversity. For instance, in the case that students of mathematics or languages with high WM capacity would show the same level of performance as marine biology students, this might indicate that WM capacity can somehow compensate for less prior knowledge (i.e., compensation effect). Moreover, if WM capacity would be a significant predictor of performance in the group of marine biology students, this might indicate an additional effect of WM capacity beyond prior knowledge. Furthermore, it is reasonable to assume that the interplay of WM capacity and prior knowledge varies in different age groups. That is to say, WM capacity as well as the amount of knowledge increases with age (e.g., Gathercole et al., 2004; John, 1985) so that it is possible that respective interaction effects might be more remarkable in younger students who are still more likely to compensate for a lack of resources. Future studies should take this moderating role of age into account.

By focusing on navigational behaviors, the present dissertation aimed to shed light on the underlying processes that might explain the relation between WM capacity and hypermedia learning. As it was found that navigational behaviors only partially mediated this association, future studies might further disentangle these underlying processes. More precisely, it is reasonable to assume that, for instance, self-regulatory skills or information processing capabilities explain part of this relationship as well, as these variables are not only strongly related with WM capacity, but also influence comprehension and learning (e.g., Kyllonen & Christal, 1990; Winne & Perry, 2000). Therefore, future studies might investigate alternative mediators (i.e., self-regulatory skills or information processing capabilities) in this context.

The finding that the multiperspective hypermedia environment supported students' performance in the simple exploration tasks more than the linear learning environment (for learners with high WM capacity) but hampered students' performance in the complex exploration tasks, raises the question of which underlying mechanisms might be responsible for these effects. More precisely, future studies should aim to replicate the present findings by additionally assessing children's on-task motivation when dealing with simple exploration tasks to disclose whether the multiperspective hypermedia environment might have been more stimulating for children with high WM capacity than the linear environment. Moreover, an inclusion of a third linear learning condition, which also demands learners to integrate information from different pages, might reveal, for instance, to what extent the fragmentation of information in the multiperspective hypermedia environment might have negatively influenced performance in the complex exploration tasks. To conclude, replication studies delving into the unexpected effects found in the present dissertation might shed more light onto the possible learning mechanisms.

Beyond the issue of finding explanations for the unexpected effects, it might additionally be interesting to further explore the effectiveness of the multiperspective learning environment about fish. In this sense, four aspects, which are worth being further explored, will be outlined in the following. First, as the multiperspective hypermedia environment did not reveal to be unconditionally beneficial for the fourth-graders examined in the present dissertation, it might be reasonable to apply this setting to different, older age groups (see also 5.2.2) in order to examine whether its effectiveness can be increased. Of course, when applying the learning environment to older students, the comprehension and learning measures would have to be adapted to the respective target group. For instance, the exploration tasks should require from learners to locate and concurrently integrate more information than before. Second, an application of other learning measures than the inferential questions or the multiperspective reasoning task would reveal which further high-level thinking processes might be stimulated by the exploration of the multiperspective hypermedia environment. In this vein, for instance, it might be interesting to include a problem-solving task (cf. Jacobson & Spiro, 1995) or a task which demands from learners to write an essay about a specific issue of the fish-topic by including diverse perspectives (e.g., evolution of the different breams; cf. Lowrey & Kim, 2009; Zydney, 2010). Third, comparing novices (i.e., students with low prior knowledge about fish) and experts (e.g., members of a diving club, employees of a sea aquarium) while exploring the learning environment might not only result in a differential effectiveness regarding learning outcomes but might also reveal different navigational approaches (cf. Lawless et al., 2003). Fourth, a focus on appropriate scaffolding measures to facilitate the exploration of the environment for learners might also be insightful. In this vein, for instance, a “support button” that indicates for every exploration task where to find specific information could be implemented in the learning environment. Moreover, it would also be interesting to examine the impact of metacognitive support by prompting students’ metacognitive reflection. More precisely, asking children during exploration to give reasons for their actual actions and navigation, might increase the children’s metacognitive awareness, which, in turn, might benefit their further exploration of the materials (cf. Bannert & Mengelkamp, 2008). In addition, it might be valuable to investigate whether an initially provided navigational training (see also ‘Exploring alternative methodological approaches’ and 5.3.2 ‘Implementation of digital learning technologies in school’) would improve children’s navigational processing in (multiperspective) hypermedia environments and, in turn, their comprehension and learning. In such a navigational training, children should be taught, for instance, effective navigational behaviors such as perspective processing or to avoid distracting information in order to reduce irrelevant processing. In sum, by taking different age and knowledge groups, further learning measures, or additional scaffolding into account, the effectiveness of the present multiperspective hypermedia environment about fish can be further explored.

Finally, it might be worth considering to what extent the present findings are generalizable to content materials other than ‘biodiversity of fish’. It is possible that by choosing a more gender stereotyped topic, such as cars for boys or horses for girls (Bjerke, Ødegårdstuen, & Kaltenborn, 1998; DeLoache, Simcock, & Macari, 2007), learning effects might be moderated by gender. Future studies should thus replicate the current research questions applying different materials.

Exploring alternative methodological approaches

The present dissertation comprised cross-sectional studies. Cross-sectional studies are less time-consuming and less costly than longitudinal studies, and are a good way to get a first impression of the associations between variables (Mann, 2003). However, although cross-sectional data has been shown to represent an adequate proxy for longitudinal data (Yorke & Zaitseva, 2013), it does not support conclusions about cause and effect of simple associations. Thus, in order to clarify causal inferences of associated variables longitudinal designs are indispensable. In the following, four suggestions about possible longitudinal designs with regard to the findings of the present dissertation will be made.

First, with regard to Study 1, future studies comprising a longitudinal design should further dwell on the relationship between WM capacity and teacher’s giftedness nominations. Specifically, as already mentioned above (5.2.1 ‘Methodological approach’), whether a child’s WM capacity influences a teacher’s decision about his or her giftedness or whether a child’s WM capacity will be improved due to teacher’s nomination and the following attendance of special promotion offers cannot be deduced from the current data. Moreover, whether teachers actually perceive a student’s WM capacity or whether WM capacity rather influences further variables such as more observable learner characteristics (i.e., verbal abilities, reading comprehension) or the student’s achievement, which is finally judged by the teacher, is also not clear. Thus, in a prospective longitudinal design several student characteristics should be assessed prior to a teacher’s giftedness nomination including WM capacity, observable learner characteristics (e.g., reading comprehension, self-regulation), the achievement of a student (i.e., standardized achievement tests as well as grades), and also further variables that might have an influence and should therefore be controlled for such as socioeconomic status (SES), gender, or age. Optimally, these characteristics should be assessed before students have been exposed to any former giftedness selection and promotion so that it can be ruled out that the students’ characteristics are already influenced by former giftedness nominations. Respective results might indicate which characteristics most strongly influence teachers’ giftedness nominations when controlling for other characteristics.

Importantly, results might also reveal whether the assumed causal direction of WM capacity on teachers' giftedness nominations actually holds true. Furthermore, in order to shed light on the intertwining between WM capacity, achievement, and teachers' giftedness judgments, a longitudinal mediation model should include at least three time points. More precisely, WM capacity (and other more observable learner characteristics) should be assessed at Time 1, achievement at Time 2, and teachers' giftedness nominations at Time 3. The results of this mediation model might indicate whether WM capacity (or rather other learner characteristics) indirectly affects teachers' giftedness nominations via achievement.

A second suggestion concerns the causal direction of the mediating effect of perspective processing on the association between WM capacity and performance in Study 3. This mediation effect needs to be studied more rigorously by verifying it in a longitudinal design. More precisely, WM capacity should be assessed at Time 1, perspective processing at Time 2, and performance at Time 3. Furthermore, baseline measures of perspective processing and performance at Time 1 should additionally be controlled for.

Third, longitudinal studies cannot only validate the conclusions from the present findings but also extend them. In this sense, and also with regard to Study 3, it might additionally be insightful to longitudinally examine whether navigational trainings (see 'Exploring the effects of hypermedia instruction') can enhance the performance of students with low WM capacity in hypermedia environments. Here, a randomized control group design with several measurement points would be most suitable. Specifically, prior to the training the students' WM capacity as well as their baseline navigational behavior in a respective setting should be assessed. Next students should be either assigned to a navigational training condition or to a control condition (i.e., not focusing on navigational behaviors). At several measurement points students should not only be compared with regard to their shift in navigational behaviors and their performance in hypermedia environments, but also with regard to their WM capacity. Results would indicate (1) whether a respective training would support students with low WM resources to adapt more effective strategies, (2) whether a respective training would enhance students' WM capacity, which, in turn, might positively affect students' navigation, and (3) how long a respective training would have to last in order to evoke beneficial effects.

Fourth, it might be insightful to examine the long-term effects of the multiperspective hypermedia environment on children's performance. Specifically, it would be worth investigating whether the significant difference between children's multiperspective reasoning performance when having either explored the multiperspective hypermedia environment or the linear environment (at least for high WM learners) would still be prevalent in a follow-up test, which could take place several weeks or even months later. The results would indicate whether the exploration of the multiperspective hypermedia environment only temporarily stimulates children's multiperspective reasoning or whether it changes their way of thinking in the long-run.

When referring to the assumed influence of contextual variables (e.g., class level) on teachers' giftedness judgments, it becomes clear that the application of conventional statistical analyses is not sufficient to simultaneously investigate the impact of contextual variables as well as of individual student variables (Geiser, 2011). In order to take the multilevel nature of these judgments into account, a multilevel modeling framework, which allows for analyzing such hierarchical data structures, should be used (Raudenbush & Bryk, 2002). In multilevel analyses, students are considered to be nested within classes. Specifically, student characteristics such as WM capacity or individual performance should be modeled on the first level (student level). At the second level, class characteristics such as mean ability (i.e., average WM capacity) or grade level should be modeled (classroom level). Multilevel analyses can indicate to what extent the proportion of total variance can be attributed to between-class differences, that is, to what extent the classroom influences teachers' giftedness decisions, or to what extent it can be attributed to within-class differences, that is, to what extent student characteristics influence teachers' giftedness decisions. Moreover, cross-level-interactions may be computed to point out how variables from different levels interact (e.g., Luke, 2004). Future studies should thus consider multilevel analyses in order to shed light on the interplay of individual characteristics and contextual influences on teachers' giftedness nominations (cf. McBee, 2006; Zettler, Thoemmes, Hasselhorn, & Trautwein, 2014). Note, however, that multilevel analyses require large sample sizes (e.g., Maas & Hox, 2004, 2005; Snijders & Bosker, 1993). Maas and Hox (2004), for instance, advice N = 50 units at the second level (i.e., about N = 1000 students at the first level given that approximately 20 students form a class) to avoid biased estimates of the second-level standard errors.

The present dissertation used tablet computers (i.e., iPads) instead of traditional computers to implement both learning environments as touch screen applications are assumed to be better adapted to the skills of younger children than traditional computers (e.g., Lu & Frye, 1992). However, whether the application of tablet computers was indeed more beneficial than the use of traditional computers is not clear. In this vein, Martin and Ertzberger (2013) reported that students showed higher achievement scores when dealing with a traditional computer than when dealing with an iPad. In line with this, Young (2014) suggested that novel learning devices such as iPads can distract students from paying attention to the content. For instance, it might be possible that a tablet computer rather invites to "play around" instead of concentrating on the content as compared to traditional computers. As children are less self-regulated than adults (e.g., Rothbart, Posner, & Kieras, 2006), it is reasonable to assume that tablet computers stimulate younger children even more to "play around" (i.e., getting distracted) and thus to achieve less than adults when using tablet computers. Hence, it may be that the children described in the present dissertation might have achieved better by using a traditional computer instead of an iPad. At the same time, however, it has also been demonstrated that using a tablet application is more exciting, encouraging, and motivating than using a traditional computer (e.g., Martin & Ertzberger, 2013; Sung & Mayer, 2013). In line with this, the results of the present study indicated that children highly enjoyed working with the iPad when they were asked about their pleasure dealing with the iPad (M = 3.81, SD = 0.41, range 1-4). Still, whether this pleasure with the iPad might have motivated the children to put more effort into solving the learning tasks or whether it rather distracted them from concentrating on the learning tasks as compared to traditional computers is unclear. Therefore, future studies could focus on a comparison between tablet computers and traditional computers, also considering different age groups, in order to find out which media application is most suitable for learning and achievement. Specifically, by taking log files (see also next paragraph) into account, studies could further explore whether these media evoke different navigational patterns, which in turn might explain higher or lower achievement. For example, it might be that log files from tablet computers reveal more "playing around" navigation (e.g., moving or zooming contents) than log files from traditional computers. Another issue, which is worth considering in future studies, addresses the influence of both media on the perceived enjoyment of the content. In this vein, for instance, the children in the present dissertation indicated that they had considerably enjoyed the content materials (M = 3.03, SD = 0.72, range 1-4). However, it might be that their judgment was influenced by the iPad use. Therefore, it would be additionally interesting to investigate whether the enjoyment of the content differs between tablet computers and traditional computers with contents being generally rated more positive when using a tablet computer than when using a traditional computer. Taken together, although tablet computers seem to be an appropriate medium to implement learning environments at first sight, its effectiveness has to be further examined by comparing it with traditional computers, especially for younger children.

The present dissertation demonstrated the crucial role of log files in order to capture the navigational processes of the children when dealing with the multiperspective hypermedia environment (see also 5.2.4 for a description of log files). In line with other studies (e.g., Barab et al., 1996), log files herein revealed to be highly predictive for learning. However, in order to interpret the resulting navigational behaviors even better, future studies should include additional process measures that can be more insightful when considering the processing of specific contents (e.g., reading a text). More precisely, whereas log files provide information about a child's specific navigational path as well as about how long he or she processes specific materials (e.g. a picture or a text), it cannot be concluded how the child specifically processes a text or a picture. In this vein, for instance, additional eye-tracking analyses could provide information about whether a child actually reads a text or whether he or she only considers a seductive picture located next to the text. Moreover, log files cannot provide information about processing intentions such as whether learners are aware of their navigational strategy or why learners decide to navigate in a specific manner. In this case, think-aloud protocols might be more insightful. To conclude, future studies should apply additional process measures to unravel the conceptually different processes that underlie hypermedia learning.

5.3.2 Implications for educational practice

Apart from suggestions for future research to further explore and validate the findings of the present dissertation, three implications for educational practice will be discussed in the following section. First, the need for a uniform definition of giftedness will be addressed. Second, the implementation of digital learning technologies in the school context will be discussed. Third, the intervention approach of ability grouping will be considered from different perspectives.

Claiming for a uniform definition of giftedness

In the introductory chapter (1.1.4), the present dissertation pointed out that in the practical context one can find several gifted identification procedures to decide whether a child may be allowed to attend specific promotion offers or not. In this vein, intelligence tests as well as teacher nominations lead the way (Friedman-Nimz, 2009; Rost & Buch, 2010). Importantly, these procedures yield partially different groups of "identified" gifted students. For instance, on the one hand, it has been found that not all students nominated as gifted by teachers have extraordinary high intelligence scores (e.g., Gear, 1976; Neber, 2004; Schulthess-Singeisen, Neuenschwander, & Herzog, 2008). In line with this, the present dissertation also found the sample of teacher-nominated gifted children to exhibit a mean IQ of "only" M = 112.26 (SD = 11.68; Study 1). On the other hand, it has also been found that many children with high intelligence are not identified as gifted by their teachers (e.g., Rost & Hanses, 1997). In line with these findings, the data of the present dissertation (Study 1) revealed that five of the 39 non-nominated children (12.8%) exhibited relatively high IQ scores (124 < IQ < 137) as compared to the other non-nominated children as well as compared to the teacher-nominated gifted children. Moreover, when using further identification measures such as, for instance, creativity tests or standardized achievement tests, the resulting group of identified gifted children might even again differ from the group of teacher-nominated gifted children or the group of gifted children identified via intelligence test. To conclude, it is reasonable to assume that the groups of gifted children attending specific promotion offers are rather heterogeneous.

The fact that there is an unsystematic application of various gifted identification procedures in the practical context – leading to heterogeneous groups of gifted children – is not surprising since there is no universal and distinct definition of giftedness that has a legal basis. In Germany, for instance, no nation-wide definition of giftedness is proposed. Consequently, various definitions and identification procedures exist. The Bavarian Ministry of Education and Cultural Affairs, for example, promotes the Munich model of giftedness by Heller (e.g., Heller, Perleth, & Lim, 2005), which constitutes giftedness as a network of intrapersonal factors, various performance areas, non-cognitive characteristics, and environmental conditions (see also 1.1.1). On the contrary, the Hessian Ministry of Education and Cultural Affairs adopts another approach by emphasizing an IQ-conception of giftedness: "Die Feststellung einer intellektuellen Hochbegabung orientiert sich als Richtwert an einem Intelligenzquotienten (IQ) von 130 bzw. einem Prozentrang (PR) von 98 in wenigstens einem Testverfahren" [*The decision as to whether a person is intellectually gifted or not depends on his or her quotient of intelligence (IQ) which has to be 130 or more or has to be in a percentile rank of 98 in at least one standardized test*] (Hessisches Kultusministerium, 2014, p. 41). Concerning the enrichment program out of which students of Study 1 were taken, namely the Hector Children Academies, the definition of giftedness is broader (and, by implication, less clear): " Die Angebote der Hector-Kinderakademien richten sich […] an alle besonders befähigten, interessierten, motivierten und kreativen Grundschulkinder […] Damit strebt die Hector-Kinderakademie im Sinne der Chancengerechtigkeit an, Enrichment-Angebote für bis zu 10% der Kinder eines Jahrgangs zu ermöglichen (p. 2)." [*The enrichment offers of the Hector Children Academies aim at promoting all gifted, interested, motivated,* *and creative elementary school children […]. In the sense of equal education opportunities, Hector Children Academies intend to provide enrichment offers for about 10% of the children of one graduate year.*] (Vereinbarung zwischen der Hector Stiftung II und dem Land Baden-Württemberg: Vergaberichtlinie für eine Hector-Kinderakademie, 2010). In line with these diverse conceptions of giftedness, Reis and Renzulli (2009) summarized the situation as follows: "gifted and talented students are indeed a diverse group of individuals […], students with varying abilities and potentials in one or many domains." (p. 233).

Unfortunately, however, this liberal and open-minded attitude towards giftedness is concurrently associated with some practical shortcomings. Specifically, when referring to ATI (Cronbach & Snow, 1977), which provides a basic theoretical assumption of the present dissertation, such a liberal attitude makes it difficult to develop learning offers that simultaneously fit to the predominant prerequisites of all children identified as gifted (cf. Zettler et al., 2014). Consequently, if a promotion offer fits to one group of gifted children, it is likely that it might not fit to another group of children who have been identified as gifted by other means. Thus, for the sake of effectiveness, learning offers have to be repeatedly adapted to the specific group of children attending a gifted promotion program. This is not only highly ineffective for developers of respective learning offers, but also for practitioners who are consistently compelled to adjust to the differing needs of the various groups of gifted children. For the purpose of developing appropriate learning offers and to guarantee an optimal promotion for gifted children, it might be necessary for educational policy to determine a universal and explicit definition of giftedness also implying uniform identification procedures. This claim for an adequate definition of giftedness including explicit guidelines about traits, behaviors, or aptitudes that describe the gifted has already been recommended a long time ago (e.g., Hodge & Cutmore, 1986). Unfortunately, however, no progress concerning a precise and uniform definition of giftedness has been made ever since. Therefore, the present dissertation agrees with current critical statements demanding a clearly defined terminology of giftedness (Carman, 2013; Siegle et al., 2010; Subotnik, Olszewski-Kubilius, & Worrell, 2011; Zettler et al., 2014). Importantly, this claim does not suggest that children who might then not be considered as gifted anymore are excluded from specific promotion offers. It merely demands distinct and clear designations to improve promotion offers. Considering the practical implementation of such an official conceptualization, it makes most sense to choose a parsimonious giftedness model, which, importantly however, includes more than only intelligence in order to comply with topical giftedness conceptions (e.g., The Munich model of giftedness by Heller et al., 2005). In this sense, for instance, the three-ring-conception of

Renzulli (2005; see also 1.1.1), which does not only demand above-average ability but also high motivation as well as high creativity, would be a suitable solution. However, the present dissertation does not presume to predetermine which giftedness conception might be best – which is rather the challenge of educational policy –, it only wants to give this debate another push.

Implementation of digital learning technologies in school

Another practical issue that can be addressed in light of the findings of the present dissertation is the usefulness of implementing digital learning technologies in the educational context. Digital learning offers, such as e-books, the internet, or instructional hypermedia environments, are increasingly advocated in the school context (e.g., Purcell, Heaps, Buchanan, & Friedrich, 2013). Particularly since the upcoming interest in tablet computers, an increased hype of innovative instructional environments in the classroom can be noticed (e.g., Falloon, 2013; Ihaka, 2013). In line with this, Hedman and Gimpel (2010) theorized that this rapid and – to a certain degree – non-reflective uptake of hyped technologies such as the iPad in the school context may be based on other than only functional values (i.e., device utility for completing a task or achieving a goal), namely on technology fascination, trendiness, fashion, or fear of being out-of-date (i.e., emotional and social values). Thus, schools rashly seem to adopt these innovative learning technologies without relating it to theories of learning or empirical findings proving its effectiveness (Falloon, 2013). In this vein, previous research has revealed that the effectiveness of complex innovative learning offers such as, for instance, hypermedia environments is limited (see Chen & Rada, 1996 as well as Dillon & Gabbard, 1998 for a comprehensive overview). Specifically, previous research claims that hypermedia instruction seems to be only beneficial for specific learning goals (i.e., higher-level thinking) and should additionally be restricted to advanced learners (cf. Clark & Mayer, 2003; Jacobson & Spiro, 1995). Note, however, that these findings do not imply that digital learning technologies are disadvantageous in general but that the effectiveness of digital learning technologies varies as a function of the particular task demand, the type of learner and, importantly, also of the specific design (e.g., linear or nonlinear, multimedia or single media). Thus, although digital learning technologies may contain some limitations or drawbacks as compared to traditional instruction (e.g., textbooks), they can also be more beneficial when taking into account some conditions (e.g., type of learners, type of task, type of design). Therefore, the question of whether these innovative devices are generally beneficial takes a back seat to the question of how to support students in benefitting the most from these innovative technologies. In the following, the present dissertation attempts to give some suggestions concerning this issue.

Based on the assumption that innovative digital technologies and thus complex learning environments will be increasingly implemented in the classroom, it is particularly necessary for teachers to train students' media skills. Although the children in the present dissertation indicated having a high expertise in computer use, including also touch-screen interfaces (M = 3.86, SD = 1.12, range: 1-4), they still appeared to struggle with the multiperspective hypermedia environment. Thus, specific media skills, including how to effectively use and navigate nonlinear learning environments, should be addressed above all. Specifically, as nonlinear environments require from learners to autonomously control their learning process, self-regulation skills, such as planning, monitoring, or controlling cognition and motivation would have to be fostered (cf. Winne & Perry, 2000). Moreover, navigational trainings about how to effectively use these learning offers are indispensable (see also 5.3.1 'Exploring the effects of hypermedia instruction'). In this vein, for instance, the present dissertation demonstrated that the navigational behavior of perspective processing was much more beneficial than the navigational behavior of content processing when conceptual knowledge was conveyed. Thus, in this case, it is important that students learn to navigate comprehensive overview pages in order to understand how different contents are related instead of getting lost in detailed contents. Furthermore, the findings of the present dissertation demonstrated that the multiperspective hypermedia application on the iPad was particularly beneficial for advanced learners (i.e., learners with high WM capacity) with regard to their multiperspective reasoning. Thus, it might be reasonable, for instance, to implement multiperspective hypermedia environments in gifted classes, when aiming to stimulate their high-level thinking skills. On the contrary, for less able children (e.g., with low WM capacity) another digital learning design might be preferable. For example, when aiming to convey knowledge about a certain phenomenon (e.g., locomotion patterns of animals or the functioning of mechanical devices such as a toilet flushing system), the use of a digital learning device (e.g., tablet computer) may also hold potential for this ability group. More precisely, the presentation of animations (visualizing the phenomenon) with concurrent audio (explaining the phenomenon) might better support the students' comprehension of a certain phenomenon than written text and static pictures (as normally presented in a textbook). Whereas the former option (animation and audio) simultaneously uses two coding systems, which is assumed to facilitate the integration of information and thus learning (Dual coding theory, Paivio, 1991; see 1.3.1), the latter option (text and pictures) demands learners to switch between to-be-integrated information which may heavily load on cognitive resources (Cognitive load theory, Sweller, 1988; see 1.3.3). Thus, digital technologies may also provide potential for less able learners if the design of these devices is adapted to the specific needs of these students.

Moreover, as learners with high prior knowledge seem to benefit more from hypermedia instruction (e.g., Jacobson et al., 1996), it would be necessary to provide learners with sufficient prior knowledge about a content area before challenging them to explore the same in a hypermedia environment. Importantly, this knowledge should be conveyed by simple linearly illustrated materials (e.g., an e-book or a film [as in the present dissertation]) as previous research has stated that linear formats are generally more effective than hypermedia formats for imparting factual knowledge (e.g., Barab, Young, & Wang, 1999; Hartley, 2001; Lee & Tedder, 2003; McDonald & Stevenson, 1996). Thus, it is important that instructors reflect beforehand on whether a nonlinear learning setting actually benefits a certain learning task or whether linearly structured materials might be more suitable. Although linearly structured materials might be less challenging than nonlinear environments, teachers should still be aware of some risks, particularly when linearly structured materials are displayed in terms of digital learning technologies such as innovative e-books on a tablet computer. More precisely, although an e-book may provide more opportunities to present the materials (e.g., with animations, sounds, or videos) as compared to a print book (e.g., Scheiter & Gerjets, 2007), it concurrently holds the risk of easily distracting learners by displaying highly interesting and entertaining contents (e.g., videos or animations), which however might be irrelevant for the current learning task (i.e., seductive details effect; cf. Harp & Mayer, 1998). Alternatively, providing prior knowledge by an informative film sequence might not only reduce the risk of being distracted by seductive details (i.e., as it implies less interactivity) but also represents a seemingly more fashionable opportunity than using a traditional print book. Indeed, compared to a print book, films imply the potential to present information more realistically, vividly, and experience-driven (Tibus, Heier, & Schwan, 2013). Moreover, learners need less mental effort to extract the information from video than from text (Salomon, 1984). However, less mental effort, in turn, is associated with a more superficial elaboration of the information that may make learners prematurely believe to have understood the information quite well (illusion of understanding; Bétrancourt, 2005). Therefore, teachers should make students aware of such risks associated with digital devices (e.g., seductive details effect, illusion of understanding) and specifically guide their learning approaches to counteract potential distractions and to avoid a too passive elaboration (e.g., by providing the students with specific tasks while watching a film).

To conclude, most important is that teachers reflect beforehand on which digital design might be most suitable for a specific learning situation (e.g., depending on the type of learner and the type of task). That is to say, if the design is appropriately chosen (e.g., adapted to the specific needs of the students), the digital learning technology may provide great potential for the learner (see ATI, Cronbach & Snow, 1977). Moreover, teachers should be aware of the risks that are associated with innovative instructional devices and should try to prevent the same by equipping their students with appropriate skills that might attenuate these risks (e.g., self-regulatory skills, navigational skills). Finally, teachers permanently have to guide and support the learning processes of their students when the latter are dealing with complex instructional designs.

Adequacy of ability grouping

The present dissertation revealed that multiperspective hypermedia environments were more effective for higher level thinking, namely for multiperspective reasoning, than linear environments, importantly however, only on condition of high WM capacity. This finding further emphasizes that students from different ability groups need differentiated instruction (ATI, Cronbach & Snow, 1977). Accordingly, ability grouping for gifted students, that is, separating them from their average peers into homogenous learner groups, seems to be an effective measure in order to optimally support these students. As already outlined in the introduction (1.1.3), ability grouping is a common promotion measure for the gifted (e.g., Hagmann-von-Arx, Meyer, & Grob, 2008). However, this approach is not unambiguously supported but considered quite controversial (e.g., Alvarez, 2007). The fact is that ability grouping for gifted has been shown to elicit the BFLPE (e.g., Lüdtke et al., 2005). More precisely, ability grouping negatively impacts the academic self-concept of gifted students in that gifted students in a gifted class show a lower self-concept than gifted students in a heterogeneous class (Marsh, Chessor, Craven, & Roche, 1995; Preckel, Goetz, & Frenzel, 2010; Preckel, Zeidner, Goetz, & Schleyer, 2008; Seaton et al., 2008). As academic self-concept, in turn, is positively associated with academic achievement (Marsh et al., 2008), academic interest (Marsh, Trautwein, Lüdtke, Köller, & Baumert, 2005), educational aspiration (Marsh, 1991), or enjoyment (Goetz, Frenzel, Hall, & Pekrun, 2008), this decrease in self-concept due to ability grouping has been considered critically (Marsh, Hau, & Craven, 2004). Nevertheless, it has to be remarked that the academic self-concept of the gifted, even after ability grouping, is still at a higher level than the academic self-concept of average students (Preckel et al., 2010). Moreover and contrary to the results above, a few studies did not even find gifted students to experience a decrease in their academic self-concept after having been grouped with other gifted students in the course of a summer program (e.g., Cunningham & Rinn, 2007; Dai, Rinn, & Tan, 2013). Furthermore, ability grouping has also been shown to be associated with socio-affective benefits such as improved social relationships or a more positive attitude towards subject matters (Neihart, 2007; Vogl & Preckel, 2014). Finally and most importantly, the achievement of gifted students, who had been grouped with other gifted students, has been shown to strongly increase (e.g., Hattie, 2002; Rogers, 1993, 2007). In this sense, Trautwein and Lüdtke (2005) state "No matter what size the pond is, the quality of the "nutrition" supplied is central to the development of the fish." Nevertheless, the present dissertation does not intend to give a definite answer to the question of whether ability grouping for gifted is advisable. Instead, this issue remains to be discussed.

5.4 Conclusion

The present dissertation investigated the interplay of giftedness, WM capacity, and hypermedia learning, thereby combining different fields of research, that is, the field of giftedness, the field of cognitive psychology, and the field of hypermedia instruction. First, it was demonstrated that WM capacity represents a crucial characteristic of teacher-nominated gifted children, even beyond intelligence. Considering similar findings with gifted children identified via cognitive achievement tests (e.g., Swanson, 2006), it is reasonable to argue that high WM capacity represents an important characteristic of gifted individuals. Thus, the construct of WM is worth to be considered more strongly in the field of giftedness. Second, results of the present dissertation revealed that WM capacity also represents an important learner prerequisite in the context of hypermedia learning. More precisely, children with high WM capacity showed higher exploration performance and learning outcomes than children with low WM capacity when dealing with a multiperspective hypermedia environment. Moreover, for specific task demands, namely for simple exploration tasks as well as for multiperspective reasoning, the multiperspective hypermedia environment turned out to be more beneficial than the linear learning environment for children with high WM capacity. However, it also has to be noted that for other task demands, namely for complex exploration tasks requiring information integration, the multiperspective hypermedia environment seemed to be overchallenging for learners, even for those with high WM capacity. In this case, the linear learning environment better supported exploration performance. Taken together, for learners with high WM capacity, (multiperspective) hypermedia environments represent learning offers that can be more beneficial than traditional linear learning offers, but only for specific task demands. Third, the present dissertation demonstrated that learners with high WM resources showed more effective navigational processing (i.e., perspective processing) than learners with low WM capacity when dealing with the multiperspective hypermedia environment. Notably, this navigational processing could partially explain the association between WM capacity and learning performance, indicating that higher WM capacity leads to more effective navigation, which in turn leads to higher learning performance. Thus, in order to enhance the benefits of hypermedia learning for less advanced learners (i.e., children with low WM capacity), trainings that convey effective navigational behaviors (i.e., perspective processing) might be a step in the right direction.

In sum, by combining different research traditions (i.e., conducting field studies in the tradition of giftedness research; using materials such as computer-based WM measures and iPad-based learning applications in the tradition of cognitive psychology and hypermedia research) the findings of the present dissertation did not only lead to extended knowledge and new ideas for future investigations in various research fields, but also to tentative conclusions for educational practice. Importantly, the present dissertation underscores the crucial role of WM capacity in several research fields related to education. Unfortunately, however, the construct of WM has often been empirically neglected in these fields. Therefore, the present dissertation does not only seek to draw attention to the meaningfulness of combining different research approaches, but also seeks to prospectively take a closer look at the construct of WM in the fields of giftedness and hypermedia instruction.

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