Using a learning management system in secondary education: Design and implementation characteristics of learning paths

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Foreword

TABLE OF CONTENTS

1 | General introduction

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Chapter 1:
General introduction

Abstract

This chapter provides a general introduction to the studies examined in this dissertation. The general aim of this dissertation was to increase the knowledge on how Learning Management Systems (LMS) are used by secondary school teachers and to examine the design and implementation of learning paths. The structure is as follows: First, the research context of the studies is clarified, and specifically its focus on the technologies used in the research chapters. Second, a theoretical framework is presented that provides the foundation for the different studies. This is followed by the research objectives of this dissertation. It concludes with a description of the methods and design of the studies (three quantitative and one qualitative studies) and a structured overview of the content of the different chapters. As will be explained, each chapter is based upon a published, accepted, or submitted ISI-indexed journal article.

Context of this dissertation

To fully understand the research problem tackled in this dissertation, the context of our research must first be described. In Flanders, a twofold higher education structure had been implemented with professional Bachelor's programs on the one hand and academic Bachelor's and Master's programs on the other. University colleges are thus more focused on professional practices, in contrast to universities which have a more academic orientation. As this dissertation has been funded by the University College Ghent, it aims at developing and reporting on a research program that is relevant for educational practice, in addition to validating conceptual frameworks to contribute to theory development and validation. As such, this dissertation lies at the nexus between educational research and educational practice.

According to perceptions about collaborative learning (Broekkamp & van Hout-Wolters, 2007), the gap between educational research and practice has been internationally recognized as problematic. A recent study in the Netherlands and Flanders concluded that educational researchers were convinced that the outcome of their research 'should be' relevant for educational practice (van Braak & Vanderlinde, 2012). This view has also been supported by the Dutch government in a scientific report 'Nationaal Plan Onderwijswetenschappen' (Commissie Nationaal Plan Toekomst Onderwijswetenschappen, 2011), in a report by the Flemish government 'Advies ten gronde over onderwijsonderzoek' (Vlaamse onderwijsraad, 2007) and as a major conference theme, such as 'Non satis scire – to know is not enough' (AERA-conference, Vancouver, 2012). In contrast, practitioners hardly have recognized the contribution from educational research (Burkhardt & Schoenfeld, 2003). Available research literature highlights critical conditions that might help to reconcile the interests of both researchers and teachers. In addition to the fact that research problems should build on actual

problems as defined by teachers (Burkhardt & Schoenfeld, 2003; Willinsky, 2001), studies have pointed to the adoption of a partnership approach when setting up research aiming to be valid for practice or having implementation relevance (Furlong & Oancea, 2013; Levin, 2013; McKenney & Reeves, 2013).

In his review paper on the relationship between research, policy and practice in education, Levin (2013) pointed out several difficulties in studying this relationship. He referred to Maclure (2004) who concluded that qualitative researchers consider themselves disadvantaged as they fear their method is regarded as less powerful, and to Miller and Pasley (2012) who stated that research evidence resulting from academic research studies is more appreciated than professional knowledge based on experience. But even more importantly, Levin (2013) referred to a series of studies reporting that teachers are more influenced by their own experience, the relationships with their colleagues and their own teaching practices than they are influenced by research, to which they attach less importance (Cordingley, 2008; Mitton et al., 2007). In response to this call for a stronger link between research and practice, and in line with recent multimedia research by Eysink, de Jong, Berthold, Opfermann, and Wouters (2009), we chose to study instructional approaches that were (1) as close to real-life examples as possible and (2) the most relevant as possible for all participants involved.

But the research problem tackled in this dissertation was also influenced by other concerns. We share, together with many teachers, the belief about the promises of the use of information technologies in education. But this promise has remained unfulfilled until now. Already in 1980, Kulik, Kulik, and Cohen (1980) looked back on twenty years of computer use in education and stated: "The dream of a computer revolution in college teaching is now almost two decades old. Soon after the computer industry started using computers in personnel training in the late 1950's, farsighted educators began dreaming about a computer age in higher education. They envisioned college classrooms in which computers would serve as infinitely patient tutors, scrupulous examiners, and tireless schedulers of instruction. Teachers in these imagined classrooms would be free to work individually with their students. Students would be free to follow their own paths and schedules in learning" (p. 525). Today – almost fifty-five years since we started using computers in education – we are still trying to realize that dream. Recent research is even less positive about the pace of technology adoption and implementation in education (Hsu, 2011). The next section discusses the technology being examined as part of the research context.

Educational technologies being studied: LMS

Starting with the review study by Cuban (2009), researchers have pointed to critical shortcomings in the current adoption of technologies in education (Drent & Meelissen, 2008). The weakly integrated adoption of technologies seems to be linked to teachers' beliefs (Tondeur, Hermans, van Braak, & Valcke, 2008), teachers' confidence level towards the potential of technologies (European Commission, 2013), lack of technological expertise and access to technology (Bingimlas, 2009), lack of pedagogical or didactical competences to adopt the integrated use of technologies (Balanskat, Blamire, & Kefela, 2006), and professional engagement (Riel & Becker, 2008). The present dissertation contributes to the empirical research base regarding the integrated use of computers in education by focusing on LMS. In addition, this dissertation aims at implementing technologies in learning and instructional processes by considering some shortcomings of earlier endeavors. In line with the above discussions concerning the nexus between research and practice, our research considers conditions that help to guarantee technology use will be evidence-based and successful.

LMS (also referred to as Virtual Learning Environments, Digital Learning Environments, Course Management Systems or Electronic Learning Environments) are web based applications, running on a server and accessible with a web browser from any location with an Internet connection. In earlier research, we noticed that LMS presents educators with the following functionalities: tools for the administrative support of learning processes (recording assessment results, agenda, document management); the facilitation of communication processes between school board, teachers, students and parents; electronic support of learning processes (knowledge collaboration, contact sessions, feedback module) and the design and implementation of course material (e.g., by bundling and/or sequencing learning objects into learning paths) (De Smet & Schellens, 2009).

Although LMS originated in the late nineties of the previous century and despite their high adoption rate in higher education (Kember, McNaught, Chong, Lam, & Cheng, 2010) and later in secondary education (Pynoo et al., 2011), little is known about the technology acceptance of LMS (Sánchez & Hueros, 2010; Van Raaij & Schepers, 2008); about how LMS influence learning (Koszalka & Ganesan, 2004); about how the use of LMS is related with teachers' and students' perceptions about teaching and learning (Joo, Lim, & Kim, 2011; Lonn & Teasley, 2009); about learning outcomes resulting from the use of an LMS, and about teachers' motivation and training for using the LMS (Keramati, Afshari-Mofrad, & Kamrani, 2011). Recent research by Schoonenboom (2014) showed why some LMS-tools are used more often than others. In addition, we (De Smet & Schellens, 2009) observed that from 376 Flemish secondary school teachers, 80% mainly used the LMS for administrative support of learning processes, as compared to only 10% who actively used functionalities such a wiki, a discussion forum or a learning path to support learning. This selective adoption level suggests teachers hardly know how to design and implement these educational tools within their teaching and learning processes, or that teachers have little knowledge about the potential of LMS functionalities. Given the considerable gap in the literature, we developed our research problem within the

context of LMS usage in secondary schools. Our first step was to understand the technology acceptance of learning management systems by secondary school teachers and to investigate the instructional use of the LMS. Consequently, the observed under-usage of specific LMS functionalities/tools determined our choice to concentrate on LMS learning paths.

'Learning paths' are a key feature of LMS. De Smet, Schellens, De Wever, Brandt-Pomares and Valcke (2014) described a 'learning path' as: "The LMS functionality to order a number of learning objects in such a way that they result in a road map for learners. Within a learning path, learning steps are structured in a general way (as a navigation map or a table of contents) or in a very specific sequenced way (e.g., 'complete first step 1 before moving on to step 2')" (p. 2). The most important building blocks of a learning path are the learning objects. Kay and Knaack (2007) defined the latter as "interactive web-based tools that support the learning of specific concepts by enhancing, amplifying, and/or guiding the cognitive processes of learners" (p. 6).

Learning objects have the potential to play a role in the way teachers teach and learners learn. However, empirical research about learning objects is scarce, particularly in secondary education (Kay & Knaack, 2008). There is also relatively little research focusing on design principles for learning objects (Balatsoukas, Morris, & O'Brien, 2008; Cochrane, 2005; Iserbyt & Byra, 2013). Dalziel (2003) argued that e-learning usually has "a well-developed approach to the creation and sequencing of content-based, single learner, self-paced learning objects," but added that "there is little understanding of how to create sequences of learning activities" (p. 593). Leacock and Nesbit (2007) additionally put forward that the design of learning objects is rarely science-based. More recently, in their research on how the design of instructional tools affects teaching and learning 'Basic Life Support' in secondary education, Iserbyt and Byra (2013) emphasized that research about the design of instructional tools is almost non-existent.

Given the lack of empirical research focusing on the adoption and usage of LMS, on how learning paths should be designed, presented, and implemented, and the lack of impact studies on student performance (Cheung & Vogel, 2013; Kay & Knaack, 2005; Nurmi & Jaakkola, 2006; Sánchez & Hueros, 2010), we concentrated in this dissertation on the adoption, the design and implementation of learning paths in an LMS by secondary school teachers and the impact of this implementation on students' learning outcomes and teachers' perceptions. As we believe that both design decisions and implementation features (group setting and group composition) can influence learning outcomes based on gender (Harrison & Klein, 2007), and the fact that our research takes place within the setting of STEM education (science, technology, engineering, and mathematics), gender was considered as a critical moderator.

Given that the purpose of this dissertation was to research how LMS are used by secondary school teachers in general and learning paths in particular, we formulated five research objectives in order to obtain a clear picture. We now will discuss the theoretical framework, followed by an extensive discussion of the research objectives.

Theoretical framework

Towards an eclectic theoretical framework

A variety of conceptual frameworks has been adopted to direct the studies in this dissertation. Some of these frameworks built on (1) school related variables, (2) on teacher related variables and processes, while others are related to the (3) nature of the design of the LMS and yet others are related to (4) the way students study in the context of an LMS.

Figure 1 depicts a graphical representation of the eclectic theoretical base, adopted in the studies of this dissertation.
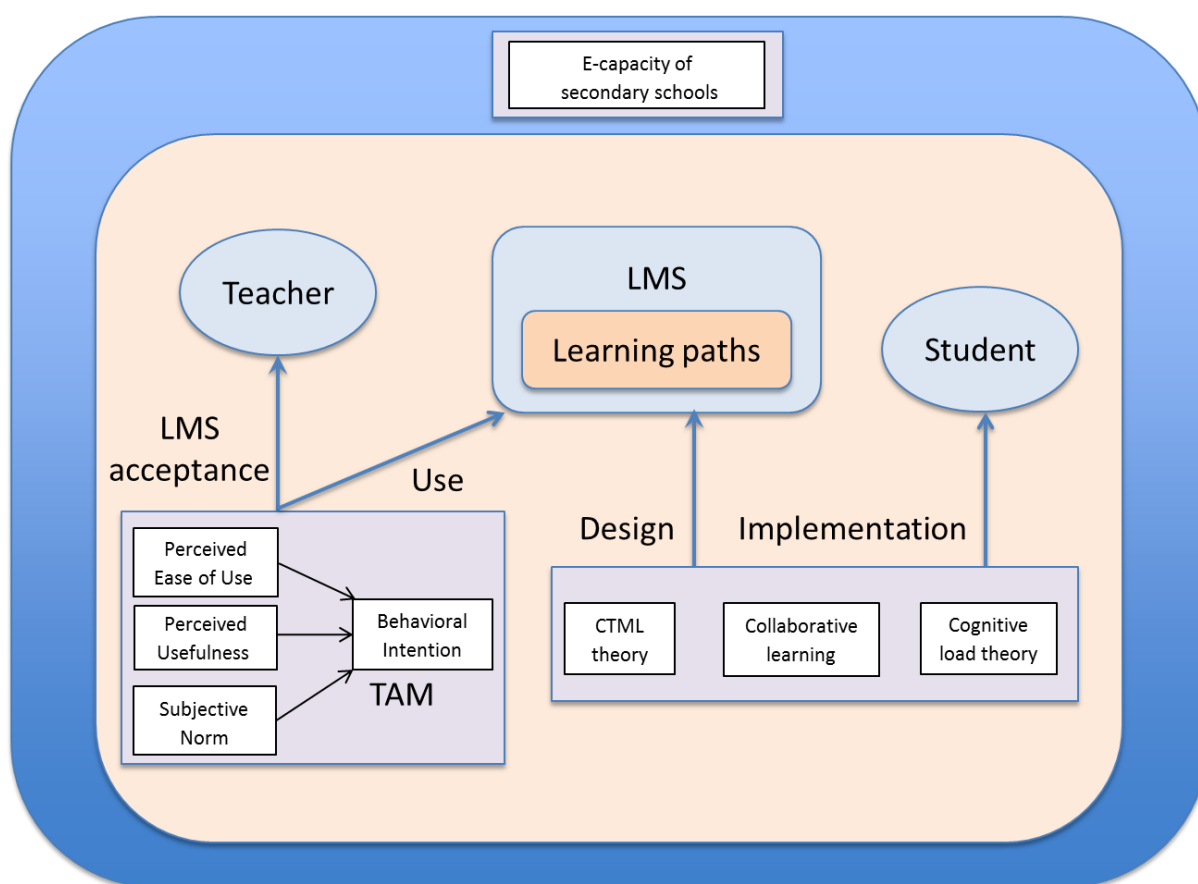
Figure 1. Eclectic framework depicting the variables and processes considered in the theoretical framework of this dissertation.

Teachers have been studied in many technology related studies. Their beliefs (Tondeur, Hermans, van Braak & Valcke, 2008), attitudes (Teo, Lee, & Chai, 2008), competences (Balanskat, Blamire, & Kefela, 2006), etc. can be related to the extent of and the nature of their technology usage in classrooms. Part of this theory-driven research is reiterated in this dissertation. In particular, we examined teachers' technology acceptance, with a focus on LMS as the particular technology. In addition, we investigated the instructional use of the LMS. We built upon the

Technology Acceptance Model (TAM) of Davis (1989) and the successor-model TAM2 by Venkatesh and Davis (2000).

As a result, the LMS was central to our eclectic framework. In addition to our focus on how the LMS is used, we investigated the design and implementation of the technology being used: LMS in general and learning paths in particular. The implementation of learning paths, or the way students study in the context of an LMS, adds students as a component to our model. To direct the design and implementation of these learning paths, we built upon the Cognitive Load Theory (CLT), the Cognitive Theory of Multimedia Learning (CTML) and on research on Computer Supported Collaborative Learning (CSCL). CLT assumes that the processing capacity in working memory of individual learners is limited (Baddeley, 1986; Sweller, 1999; Sweller, van Merriënboer, & Paas, 1998; van Merriënboer, 1997). This should be considered when developing learning materials via learning paths. The CTML includes additional design guidelines postulated by Mayer (2001, 2003, 2005). CTML has proven to be relevant for designing multimedia learning materials, such as the learning objects in our learning paths. Whereas CLT and CTML stress cognitive processing at the individual level, we added collaborative learning as the key to unlock additional learning capacities. In doing this, we built upon research and conceptions derived from the field of CSCL.

Last, our eclectic framework – as stated earlier – can be linked to the e-capacity framework of Vanderlinde and van Braak (2010) because we focused on (1) school related and (2) teacher related conditions to research how they affect the use of LMS, and learning paths in particular. These theoretical components are described in more detail below.

Technology Acceptance Model

Early theories, such as the Theory of Reasoned Action (TRA; Figure 2.1) of Fishbein and Ajzen (1975), introduced descriptive models to study individuals' behavioral intentions. According to TRA, someone's behavior is primarily determined by his or her intention to perform that behavior. This intention is, in turn, influenced by two factors, namely a person's attitude toward performing this behavior and the perceived social pressure (or subjective norm) to engage in the action.
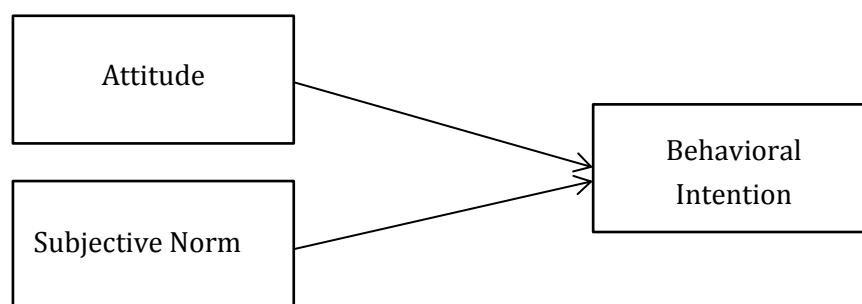
Figure 2.1 Theory of Reasoned Action (Fishbein & Ajzen, 1975)

Ten years later, Davis (1989) presented the TAM, an adaption of the TRA, especially in view of explaining the acceptance of new technologies. According to Davis, intended behavioral intentions imply two primary and direct – but related – predictors: perceived usefulness (e.g., the idea that using a specific technology will increase one's job performance) and perceived ease of use (e.g., the belief one has that using a specific technology will not require much effort).

TAM2 (Venkatesh & Davis, 2000), a later version of TAM, additionally included the original TRA-variable subjective norm as the attitude construct (Figure 2.2).
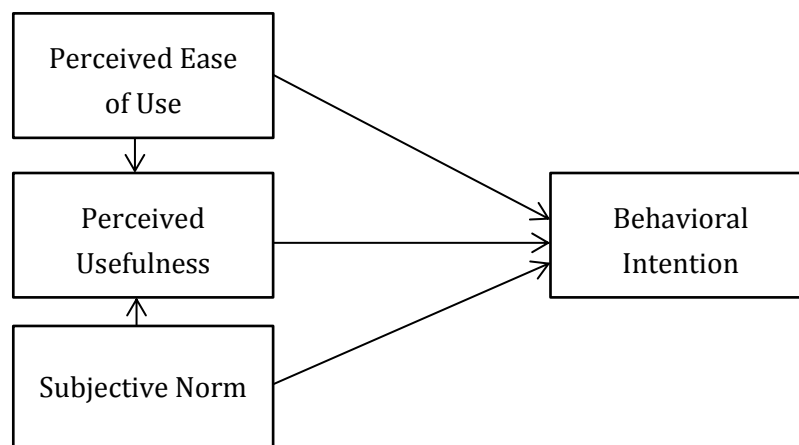
Figure 2.2 TAM2 (Venkatesh & Davis, 2000)

TAM (Davis, 1989) and its successor TAM2 (Venkatesh & Davis, 2000) received a lot of attention in the literature (Sun & Zhang, 2006). Comparative studies confirmed the supremacy of the TAM over other intentional behavior models and theories (Matthieson, 1991). Legris, Ingham, and Collerette (2003) concluded that TAM has been widely adopted with different technologies and in various contexts and successfully predicted 40% of a system's use. A comparable TAM framework was adopted in this dissertation as in earlier studies about LMS acceptance (Sánchez & Hueros, 2010; Van Raaij & Schepers, 2008). In Chapter 2, we built on a TAM2-model with extended variables, to construct and research a prediction model. Results are discussed in Chapter 6.

Given the technology being studied, a specific TAM framework was adopted and extended with more variables to increase and broaden its validity (see also Sánchez & Hueros, 2010; Van Raaij & Schepers, 2008). Additional variables included (1) personal innovativeness towards IT (Agarwal & Prasad, 1998), (2) internal ICT support (Tondeur, Van Keer, van Braak, & Valcke, 2008) and (3) experience (Sun & Zhang, 2006). Personal innovativeness towards IT was defined by Agarwal and Prasad (1998) as the willingness of an individual to try out any new information technology and has repeatedly been proven to be an important predictor of technology acceptance (Lewis, Agarwal, & Sambamurthy, 2003). Regarding ICT-support, Tondeur, Van Keer, van Braak, and Valcke (2008) found a significant and strong association between teachers' perceptions of school-based ICT support and actual classroom use of ICT. The third variable, experience, was defined as the number of years teachers have worked with an LMS, and was

introduced because the level of experience is the best-studied variable in TAM (King & He, 2006).

A last major adaptation was the redefinition of behavioral intention in the model. We cannot really focus on 'intentions to use' an LMS, since the technology is already used on a daily basis by many teachers. Therefore, we adapted the self-reported use of the LMS as also suggested by Schillewaert, Ahearne, Frambach, and Moenaert (2005) and van Raaij and Schepers (2008). In Chapter 2, we elaborated on this TAM2-model with extended variables, to construct and research our predictive model.

Cognitive Load Theory

CLT builds on the assumption that the processing capacity of working memory of individual learners is limited, which is in contrast to the unlimited capacity of long-term memory (LTM) (Baddeley, 1986). CLT also builds on the assumption that information within working memory is organized as schemas (Sweller, Van Merrienboer, & Paas, 1998). According to the authors (Sweller et al., 1998), "a schema categorizes elements of information according to the manner in which they will be used" (p. 255) and are easily stored in and retrieved from LTM.

Information processing can occur consciously or automatically (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Automatic processing occurs after extensive practice and results in freeing up working memory, while conscious processing occurs in working memory itself and requires memory resources, potentially invoking cognitive load. This is especially the case when new information is not well structured, too abundant, or not well represented. CLT distinguishes between three types of cognitive load: intrinsic, extraneous, and germane cognitive load (Sweller et al., 1998; Valcke, 2002). Intrinsic cognitive load is related to the complexity of the information (number of elements and the interrelations between them) and can as such not be avoided; however it can be mitigated by expertise (Van Merriënboer & Ayres, 2005). Germane cognitive load refers to the effort required to construct schemas, and as such is critical for individuals to tackle the new information. Extraneous cognitive load is invoked when information is not adequately presented and should be avoided.

CLT challenges instructional designers to design learning material that results in meaningful learning but does not put an overwhelming cognitive burden on working memory (Kirschner, 2002; Sweller, 1999; van Merriënboer, 1997). Paas, Tuovinen, Tabbers, and Van Gerven (2003) stated that "because intrinsic load, extraneous load, and germane load are additive, it is important to realize that the sum of intrinsic, extraneous, and germane cognitive load, should stay within working memory limits" (p. 65). Given the fact that intrinsic load is inherent to the task, and germane cognitive load is required for schema construction, instructional designers should make sure that the intrinsic load matches the knowledge and skill level of the learners and controls for extraneous load. Different approaches have been researched to handle extraneous cognitive load in order to induce germane load (Van Gog, Paas, & Van Merriënboer, 2006), such as worked-out examples or a step-by-step solution to a problem or task (Van Gog, Paas, & Merriënboer, 2006), the split attention effect which advises against formats that require

learners to split their attention between several sources of information (Kalyuga, Chandler, & Sweller, 1999) or the modality effect which suggests presenting multimodal information – e.g., partly visual and partly auditory – (Penney, 1989). Many of these related studies build on the CTML (Mayer, 2001, 2003, 2005). CTL is discussed further in Chapters 3 and 4, in order to study the design and implementation of learning paths.

Cognitive Theory of Multimedia Learning

Instructional designers recognized the need for learning materials that consider the potential drawbacks resulting from cognitive load (Mayer & Moreno, 2003). Numerous related research has been done building on CTML, as postulated by Mayer (2001, 2003, 2005). This theory represents a framework to direct instructional design of multimedia materials by defining a series of practical guidelines to design multimedia learning materials.

CTML, as can be seen in Figure 3, starts from three basic assumptions (Mayer, 2003): the dual channel assumption, the limited capacity assumption, and the active learning assumption. The dual channel assumption is derived from the research of Paivio (1978, 1991) and Baddeley (1992). Central to this assumption is that two separate information processing systems are active to process both visual (e.g., text, images) and verbal (audio) representations. The limited capacity assumption builds again on the work of Baddeley (1992) and Baddeley, Gathercole and Papagno (1998). It states that the amount of processing that can take place within the visual and auditory processing channel is limited (see above). The active learning assumption builds on Wittrock's (1989) generative learning theory and implies that the learner is actively engaged in processing information and mentally organizes it (Figure 3). Cognitive processes involved include selecting (visual/audio), organizing (mental representation), and integrating (visual, audio, and prior knowledge). We referred especially to CTML in Chapters 3 and 4 where it is discussed further in order to study the impact of learning path design and implementation.
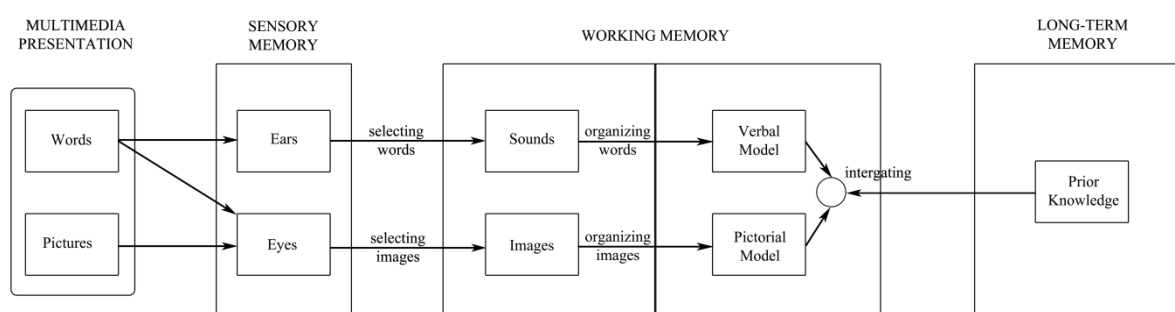
Figure 3. Cognitive Theory of Multimedia Learning (Mayer, 2005). Retrieved from http://commons.wikimedia.org/wiki/File:Cognitive_Theory_of_Multimedia_Learning_(Mayer,_2 005).png Made available under Creative Commons License.

Collaborative learning

This theoretical component of our framework was adopted since we sought to design alternative learning paths that require learners to work together. 'Collaborative learning' refers to the engagement of all participants in solving a problem together (Roschelle & Teasley, 1995). However, available empirical evidence stresses that putting learners in a group does not guarantee spontaneous collaboration (Cohen, 1994), productive interactions (Barron, 2003), or effective learning behavior (Soller, 2001). As a result, instructional support is needed to scaffold or script the collaborative learning process (Kollar, Fischer, & Hesse, 2006). When designing these online collaborative learning settings, we can build on a considerable amount of research available in the field of CSCL.

Adopting collaborative learning in the context of learning paths, can – from a theoretical perspective – again be linked to CLT. Kirschner, Paas, and Kirschner (2009) found that groups can be considered as information-processing systems containing multiple working memories, and as such, create a collective working space where cognitive load can be divided among the learners. In this view, groups are favored against individuals who can only rely on their individual working memory. Furthermore, when the group work is well structured (e.g., building on strongly elaborated and structured learning objects in the learning path), it reduces extraneous cognitive load and helps learners maximize cognitive processes that result in schema construction (Sweller, Van Merrienboer, & Paas, 1998), and thus, higher learning outcomes.

Both Chapters 3 and 4 develop in more detail how collaborative learning was designed and implemented in the learning paths. In Chapter 5 we discuss teachers' perceptions about collaborative learning, as implemented in our LMS based learning paths.

E-capacity framework
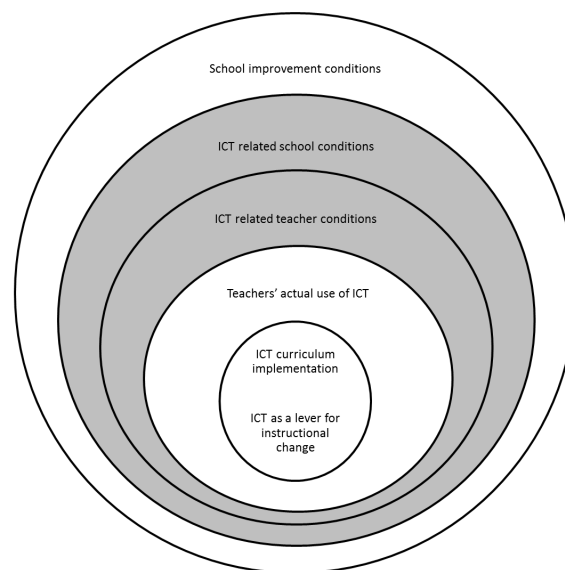
Figure 4. Model based on the e-capacity framework of Vanderlinde and van Braak (2010, p. 254).

The last theoretical component of our framework is relevant in this context to introduce more recent conceptions about ICT in education. In particular, we utilized the e-capacity framework of Vanderlinde and van Braak (2010). The e-capacity framework emphasizes four mediating concentric circles that define conditions to support ICT use in education: school improvement conditions, ICT related school conditions, ICT related teacher conditions and teachers' actual use of ICT. School improvement conditions, such as leadership, participation, and collegiality, are conditions that support the school-development process in order to help realize educational change. ICT related school conditions are subdivided by the authors into ICT support (technical and pedagogical support, often tasks performed by a dedicated ICT coordinator), ICT infrastructure (comprising hardware, software, connectivity, peripherals, and access to and availability of ICT related resources), and ICT policy plan (the schools' ICT vision as expressed by the school team, and usually made explicit via an ICT policy plan). ICT related teacher conditions refer to a teacher's professional development on ICT (internal and external ICT training courses) and teachers' ICT competencies (knowledge, skills and attitudes about the use and integration of ICT in the classroom). The teachers' actual use of ICT takes into account three types of ICT use in a classroom and was based on revised scales by Tondeur, van Braak and Valcke (2007): the use of basic ICT skills (e.g., correct use of the keyboard and the mouse), ICT as learning tool (using computers to practice knowledge or skills) and ICT as an information tool (e.g., using computers to select and retrieve information).

In the context of the present dissertation we did not focus on all conditions that help to guarantee more successful ICT usage, since it was not possible – within the scope of one dissertation – to tackle all related variables and processes. We focused on variables and ICT related processes that are limited to the circles at the school and the teacher level (see Figure 4, grey colored).

Research objectives

All research objectives in this dissertation were interlinked and did influence the design of the subsequent empirical studies. Each of the objectives was discussed in a separate chapter, except from Chapter 2 that dealt with two objectives.

TAM-based models have already been used to understand and predict LMS acceptance in non-educational (Ong, Lai, & Wang, 2004) and educational settings (Ngai, Poon, & Chan, 2007; Sanchez & Hueros, 2010). Legris, Ingham, and Collerette (2003) concluded as a result that TAM successfully predicted 40% of LMS use. However, several authors (e.g., Agarwal & Prasad, 1998; Sanchez & Hueros, 2010; Schillewaert et al., 2005) urged including additional variables to increase and broaden the validity of TAM models. This led to the first research objective:

Research objective 1 (RO1): Research the technology acceptation of LMS by secondary school teachers, based on a conceptual acceptance model including: perceived usefulness, perceived ease of use and subjective norm (traditional TAM2 components), personal innovativeness towards IT (Agarwal & Prasad, 1998), internal ICT support (Tondeur, Van Keer, van Braak, & Valcke, 2008), and experience (Sun & Zhang, 2006).

In this dissertation we examined how secondary school teachers use LMS. We scrutinized LMS functionalities available and used by our target group when adopting one of the three most often used LMS: Dokeos, Blackboard, and Smartschool (De Smet & Schellens, 2009). The following functionalities were included: document publishing (the teacher uploads documents such as presentations, course documents, video clips, etc.), announcements (the teachers send announcements or messages, that appear on the platform and/or are sent to the student's mailbox), uploading or publishing exercises (equal to document publishing, but specifically for exercises), receiving student products (the student uploads documents to be downloaded by peers and/or the teacher), assessment modules (student assignments with the possibility to get feedback from teacher), chat (synchronous communication), learning path (road map for learners), forum (asynchronous communication environment), wiki (type of website, mostly powered by wiki software, that allows the creation of interlinked websites), agenda, reservations module (material or classrooms) and student tracking module (absences or grading). Based on earlier research (Dabbagh & Bannan-Ritland, 2005; Dabbagh & Kitsantas, 2005; Lonn & Teasley, 2009) several types of LMS-use could be delineated. However, we mainly built on this context according to Hamuy and Galaz (2010) who differentiated between two types of LMS functionalities: 'informational use' versus 'communicational use'. The 'Informational' level was defined by Hamuy and Galaz (2010) as "contents published by users in the LMS" (p. 171); the 'Communicational' level was defined as "the processes that foster the exchange of these contents between LMS users" (p. 171). Hence, the second research objective was:

Research objective 2 (RO2): Examine instructional use, and more specifically the relationship between informational use and communicational use, and the question of whether informational use is required to foster the adoption of communicational use within an LMS.

Based on the empirical results obtained when answering research objectives 1 and 2 and the observation that only 10% actively used the learning path module (De Smet & Schellens, 2009), we focused subsequently on how learning paths are designed and implemented. Though Kay and Knaack (2008) emphasized the potential of LMS, available empirical research is scarce, especially in secondary education and focusing on the design and implementation of LMS and related student performance outcomes (Nurmi & Jaakkola, 2006). Gender was considered a critical moderator, given our focus on science education and the clear gender gap within STEM-education and given the fact that both design decisions (Super & Bachrach, 1957; Wai, Lubinski, & Camilla, 2009) and group setting can influence learning outcomes based on gender (Harrison & Klein, 2007). We acknowledged the research gaps discussed, and built on the CTML guidelines (Mayer, 2003, 2005) and on research about collaborative learning to direct research in view of a third research objective:

Research objective 3 (RO3): Investigate whether a particular design and implementation of learning paths has a beneficial impact on learning outcomes, and gender as a moderator.

The outcomes of the study related to objective 3 were used to direct the subsequent study. The results of the previous study were less conclusive regarding the beneficial effect of collaborative learning. Building on the literature, discussion of the results pointed at mediating variables related to group composition (Resta & Laferrière, 2007), the role of gender within group composition (Johnson & Johnson, 1996) and the tendency for females to be less active in certain group settings (Felder, Felder, Mauney, Hamrin, & Dietz, 1995). This inspired a new research question, in which conventional instruction in the control condition was contrasted with studying a variety of learning path designs in the experimental condition. This fourth research question was:

Research objective 4 (RO4): Undertake a comparative study of learning paths and conventional instruction in a learning management system, considering a collaborative or individual learning approach, with variations in group composition and gender as an important moderator.

The former research objectives and related studies hardly focused on the way teachers perceive and use the LMS and the learning paths. Therefore, we shifted our attention back to the teacher and interviewed sixteen secondary school teachers who also participated in Chapters 3 and 4. As a result, a qualitative study was designed for research objective 5:

Research objective 5 (RO5): Report on teacher perception of learning paths usage within an Learning Management System (LMS), and its relation to conditions at the school, teacher and student level, and how this affects the adoption of learning paths.

Overview of the consecutive studies

This dissertation was structured in six chapters, of which four chapters were based on empirical studies. These four chapters were based on articles that have been published or submitted for publication in ISI-indexed journals.

In their literature review about the evaluation of learning objects – which can be considered the building blocks of learning paths – Kay and Knaack (2009) put forward several critiques that inspire clear design directions for research. First, they criticized that earlier research focuses too often on single learning objects as the unit of analysis. Second, few evaluation studies adapt formal statistical analyses of the research findings; also research samples are too small and assessment tools poorly designed. This affects the validity and reliability of the research findings and the generalizability of the conclusions. Third, most evaluative research is set up in the context of higher education. Fourth, qualitative research is mainly based on descriptive data and anecdotal reports. In addition, only two studies could be found that focused on teachers' attitudes towards usage of learning objects in classrooms (Kay & Knaack, 2008).

Given the input of Kay and Knaack (2008, 2009), and considering the research objectives and our conceptual framework, both quantitative and qualitative methods were used to study the adoption and implementation of learning paths in an LMS by secondary school teachers. The dissertation was based on three quantitative and one qualitative studies. An overview of the research objectives, methodology, research design, data collection, and research techniques is presented in Table 1.

Table 1.

Research Objectives, Methodology, Research Design and Data Collection, and Research Techniques for the Different Studies

Chapter	Research objective	Methodology	Research design Data collection	Research techniques
1	General introduction (research context, purpose of study, research design, and overview of the dissertation)			
2	RO1 and RO2	Quantitative research	Teacher survey of 505 teachers	EFA, CFA (SPSS), Correlational analysis (SPSS) Path analysis (AMOS)
3	RO3	Quantitative research	Learning path study with 8 teachers and 360 students. A 2 x 2 factorial design was adopted.	Repeated measures multilevel modeling (MLwiN)
4	RO4	Quantitative research	Learning path study with 15 teachers and 496 students	Repeated measures multilevel modeling (MLwiN)
5	RO5	Qualitative research	Interviews with 16 secondary school teachers	NVivo matrices
6	General conclusion and discussion (overview and discussion of main results, limitations and suggestions for future research, and implications of the dissertation)			

Chapter 1 is the present introductory chapter in which the research context for this dissertation was explained, and – in addition to an introduction to the particular technology being studied – the focus was on the theoretical and conceptual base. The latter integrated literature about technology acceptation, the CLT, the CTML, research on collaborative learning and the e-capacity framework. Research objectives were derived and the research design of the consecutive studies was specified.

The first and second research objectives were tackled in the research reported in Chapter 2: 'Researching instructional use and the technology acceptation of learning management systems by secondary school teachers.' This chapter aimed at understanding technology acceptance of LMS by secondary school teachers and investigated the instructional use of LMS, distinguishing between informational use and communicational use. The study was based on a teacher survey administered to a sample of 505 Flemish secondary school teachers from 72 schools and stratified by province and educational network. The chapter built on the TAM framework that was extended with additional variables. Exploratory and confirmatory factor analyses, correlational analysis and path analysis were conducted. Several implications and practical recommendations for secondary school managers and LMS coordinators were formulated. This chapter was published in Computers & Education (2012).

Chapter 3 'The design and implementation of learning paths in an LMS' focused on research about the third research objective and presented the results of empirical research about using

learning paths in a secondary education setting. The quasi-experimental study took place in the context of a biology course. Twenty-nine different classes, involving 360 secondary school students, were selected at random to participate in particular research conditions of the study. All biology teachers ($N = 8$; 3 males, 5 females) teaching in the third grade of the six participating schools were willing to take part in the study. A 2 x 2 factorial research design was adopted. Learning activities (1) differed in design and (2) were either undertaken individually or collaboratively. Gender was considered as a critical moderator given the focus on science learning. Multilevel analyses were applied to study the impact on learning outcomes according to the design of learning paths, the individual/collaborative setting, and gender. The results were helpful to direct research about the design and implementation of learning paths in a secondary school setting. This chapter was published in Interactive Learning Environments (2014).

Chapter 4 'The differential impact of learning path based vs. conventional instruction in science learning' built on the findings of the study reported in the previous chapter. A second empirical piece of research on learning paths in a biology course was conducted. Fifteen teachers ($N = 15$; 5 males, 10 females), working in 13 different secondary education schools participated in the study. Six of them had prior experience with learning paths (De Smet et al., 2014). Thirty-two classes were involved in the study, and 496 third grade students were assigned to either learning path based or conventional instruction. In addition, variations in group setting and group composition were considered. Given the focus on science learning, gender was considered again as a critical variable. Multilevel analysis was applied to analyze the impact of the instructional formats, the group setting, the group composition and gender on learning outcomes. The findings resulted in guidelines for teachers who wish to implement learning paths within a learning environment design and showed evidence for the added value of learning paths as an instructional method. This chapter was – after a first review – resubmitted to Computers & Education (2015).

In order to pursue the fifth research objective, a qualitative study was designed as described in Chapter 5: 'A qualitative study on learning and teaching with learning paths in a learning management system' presenting the findings of a qualitative study about the adoption and implementation of learning paths in an LMS. The study investigated teachers' experiences and perceptions when using an LMS enhanced with learning paths. Sixteen secondary school teachers who participated in Chapters 3 and 4 were interviewed using in-depth semi-structured interviews. These interviews were analyzed using NVivo (Coniam, 2011). Several barriers were identified at the school and teacher level preventing the successful implementation of learning paths in secondary education. The article documented in this chapter was submitted to the British Journal of Educational Technology (2015).

Chapter 6 synthesized the findings of the previous chapters and offered a general conclusion and discussion, related to the research objectives. Limitations of the dissertation and directions for future research were discussed. Finally, theoretical and practical implications were presented.

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2 | Researching instructional use and the technology acceptation of learning management systems by secondary school teachers

This chapter is based on:

Chapter 2:
Researching instructional use and the technology acceptation of learning management systems
by secondary school teachers

Abstract

The aim of this large-scale study was to understand the technology acceptation of learning management systems (LMS) by secondary school teachers and to investigate the instructional use of LMS, distinguishing between informational use and communicational use. The predictive model further includes: perceived usefulness, perceived ease of use, subjective norm, personal innovativeness in the domain of information technology, experience and internal ICT support at school level. Data were collected from 505 Flemish secondary school teachers. After performing satisfactory reliability and validity checks, the study was able to support almost all of the relationships among the 9 variables. Both perceived ease of use and perceived usefulness were found to be strongly related to informational use, which in turn was found positively associated with communicational use. Internal ICT support does not significantly affect the informational use of the LMS, but is positively associated with subjective norm. Implications stress that secondary school managers in education should take into account the importance of a teachers' efforts and performance perceptions and the impact of internal ICT support on LMS adoption.

Introduction

Technology acceptance

Learning Management Systems (LMS; also referred to as Virtual Learning Environments, Digital Learning Environments, Course Management Systems or Electronic Learning Environments) are web based applications, running on a server and accessible with a web browser from any place with an Internet connection. LMS give educators tools to create online course websites, and provide access to learning materials (Cole & Foster, 2008). LMS find their origins in the late nineties. The current commercial market leader Blackboard was founded in 1997. Their open source opponent Moodle was established in 1999 (Delta Initiative, 2009). At the start, individual educators also adopted 'home-made' solutions, combining a number of basic tools such as navigation, text forums, roles, etc. By 2004, most universities felt a need to centralize their elearning systems and moved to a single, centrally hosted and supported environment (Weller, 2010). Today, most LMS provide a number of basic features and a set of specific tools and functionalities to support learning.

Recent research shows that there has been a permanent market rise in the use of LMS in higher (Kember, McNaught, Chong, Lam & Cheng, 2010) and secondary education (De Smet & Schellens, 2009; Pynoo, Devolder, Tondeur, van Braak, Duyck & Duyck, 2011). The last Educause Report confirms that almost 90% of all responding American universities and colleges reported the availability of an LMS and related support for faculty and students (Arroway, Davenport, Xu & Updegrove, 2010).

Despite this high adoption rate, little is known how LMS benefit learning (Koszalka & Ganesan, 2004), how the use of these systems is related with teacher and student perceptions about teaching and learning (Lonn & Teasley, 2009), or about the technology acceptance of LMS (Van Raaij & Schepers, 2008; Sánchez & Hueros, 2010). In the current article, the objective is to research the reasons behind the technology acceptation of learning management systems (LMS) by secondary school teachers, and to investigate the instructional use of the LMS-use within this group of teachers.

Early social theories, like the Theory of Reasoned Action (TRA) by Fishbein and Ajzen (1975), introduced descriptive models to study individuals' intended behavior. According to this theory, someone's behavior is primarily determined by his or her intention to perform that behavior. This intention is, in turn, influenced by two factors, namely the person's attitude toward performing this behavior and the perceived social pressure to engage in action.

In line with the Technology Acceptance Model (TAM) of Davis (1989), intended behavior involves two primary and direct related predictors: perceived usefulness (e.g., using a specific technology will increase their job performance) and perceived ease of use (e.g., using a specific technology will not require much effort).

To predict the acceptance of new technologies, TAM and its successor TAM2 (Venkatesh & Davis, 2000) received a lot of attention (Sun & Zhang, 2006). Comparative studies confirm the supremacy of the TAM over other intentional behavior models and theories (Matthieson, 1991). Legris, Ingham, and Collerette (2003) concluded that TAM has been widely adopted with different technologies and in various contexts and successfully predicted 40% of a system's use.

LMS acceptance

TAM-based models have already been used in a number of studies to understand and predict LMS acceptance in non-educational (Ong et al, 2006) and educational settings (Ngai et al., 2007; Sanchez & Hueros, 2010). Ngai, Poon, and Chan (2007), for example, studied the adoption of WebCT (a LMS acquired by Blackboard Inc in 2006) by university students with a TAM-based model, which was enriched with the variables technical support and attitude. As explained by Davis (1989), attitude is the degree to which the user is interested in specific systems. They found that perceived ease of use and usefulness were the dominant factors to predict LMS usage. Van Raaij and Schepers (2010), who studied the acceptance of the LMS by 45 Chinese managers enrolled in an executive MBA program, added that TAM does hold across cultures.

In the present study, a comparable TAM framework was adopted as in earlier studies about LMS acceptance (Van Raaij & Schepers, 2008; Sánchez & Hueros, 2010), but the framework was extended with additional variables to increase and broaden the validity. We focus in this extended model on the self-reported use of the LMS and not on the intentions for future use, as done in the majority of TAM-studies. Schillewaert, Ahearne, Frambach, and Moenaert (2005) and van Raaij and Schepers (2008) argued that there is no further need to focus on 'intentions to use' the LMS, because the technology is already used on a daily base.

Theoretical development

Research model

The current research model is based on TAM2, an extended version of TAM enriched with the variables perceived usefulness of LMS, perceived ease of use of LMS and subjective norm. In the past, these TAM2 variables were not able to fully predict a system's use; therefore a search for additional factors was required (Ong et al., 2003). Sun and Zhang (2006) state in this context that TAM studies call "for the inclusion of additional factors that reflect real world settings and conditions" (p. 55) and "for more research attention to individual and contextual factors" (p.54). Tondeur, Valcke & van Braak (2008) reasoned that in this brand of research, teacher and school characteristics should be considered.

In this study we examine how secondary school teachers use their LMS. We scrutinized the functionalities available in the three most often used LMS in our target group, i.e. Dokeos, Blackboard and Smartschool (De Smet & Schellens, 2009). The following functionalities were included: document publishing (the teacher uploads documents such as presentations, course documents, videoclips, etc.), announcements (the teachers send announcements or messages, that appear on the platform and/or are sent to the student's mailbox), uploading or publishing exercises (equal to document publishing, but specifically for exercises), receiving student products (the student uploads documents to be downloaded by peers and/or the teacher), assessment modules (student assignments with possibility to get feedback from teacher), chat (synchronous communication), learning path (road map for learners), forum (asynchronous communication environment), wiki (type of website, mostly powered by wiki software, that allows the creation of interlinked websites), agenda, reservations module (material or classrooms) and student tracking module (absences or grading).

In earlier research, LMS-use has been characterized in alternative ways. Dabbagh and Kitsantas (2005) and Dabbagh and Bannan-Ritland (2004) distinguished between the following functionalities and tools: collaborative and communication tools (e-mail, discussion forums, and chat tools), content creation and delivery tools (upload course content and tools to access them), administrative tools (course information, functions, interactions, and contributions) and assessment tools (assessment, tracking, posting grades etc.). Lonn and Teasley (2009) made a distinction between: materials management (organize course content, such as syllabuses, lecture slides, and exercises), interactive teaching (communication between the teachers and their

students via announcements or assignments) and peer learning (peer review, group projects, and student wikis). Hamuy and Galaz (2010) differentiate between two broad types of LMS functionalities. These two categories build further on the five levels of LMS interactions as proposed and applied in a UNESCO/IESALC's cross-national research (Silvio et al., 2004). Each consecutive LMS level allows for a deeper level of interaction (Table 1).

The 'Informational' level is defined by Hamuy & Galaz (2010) as contents published by users in the LMS (p. 171), the 'Communicational' level is defined as the processes that foster the exchange of these contents between LMS users (p. 171). With this categorization Hamuy & Galaz (2010) could track down different LMS usage by students and teachers. They observed an emphasis on Informational LMS use (89%). Similar results were reported by Nijhuis and Collis (2003), De Smet and Schellens (2009), Guthrie and Prats-Planagumà (2010) and by Malikowski, Thompson and Theis (2007), whose research will be briefly described in section 2.2 below.

Table 1.

Adaptation of the five levels of LMS interaction by Hamuy and Galaz (2010)

	Informational Level
Presence	Delivery of data or information that is limited to the syllabus of the course
Informative interaction	Offering some additional data on the operative and practical processes of a course, such as calendar and announcements
Consultative interaction	Accessing information without feedback possibilities, such as downloading or linking readings, presentations and statistics
	Communicational Level
Communicational interactivity	Allowing the user to access spaces of synchronous or asynchronous communication
Transactional Interaction	Making complex interactions that support social construction of knowledge, such as forums, assessments or chats

The primacy of Informational LMS use

West, Waddoups, and Graham (2006) found that teachers usually don't use all LMS features right from the start. They rather experiment with individual features that directly address particular instructional goals or an organizational need. When LMS features meet these goals or needs, some teachers start experimenting with other LMS functionalities. This is congruent with early technology innovation research. Nambisan, Agarwal and Tanniru (1999) found e.g., that users need to acquire a basic factual knowledge level about technology before they are able to move on. This critical need for an initial – basic knowledge - phase, has been extensively researched within the innovation diffusion literature to better understand emergent IT use (Ahuja and Thatcher, 2005). In this context, Robinson, Marshall, and Stamps (2005) argue that innovative individuals focus on news about the technology of their interest. Having worked with a variety of similar technologies, they become able to draw parallels and become capable to adapt quickly to other– more advanced - systems. In educational contexts, Tondeur et al. (2008) found that teacher's adoption of ICT first focused on "basic computer skills" (p. 498). In addition they observed that "availability of computers in the classroom" (p. 498) was a critical precursor of later adoption of ICT as a learning tool.

Malikowski, Thompson and Theis (2007) distinguish three levels of adoption with respect to CMS features: Level 1, consisting of the most commonly used CMS features such as transmitting course content; Level 2, comprising features with moderate adoption such as evaluating students, courses and instructors; and Level 3, including the least adopted features like creating class discussions and computer-based instruction. Level 1 features can be seen as features focusing on what Hamuy and Galaz (2010) refer to as the informational level, while level 2 and 3 correspond with the communicational level (Hamuy & Galaz, 2010). Between these levels, Malikowski, Thompson and Theis (2007) found a sequence of adoption decisions with Level 1 on top, Level 2 in the middle and Level 3 at the bottom. They concluded that Level 1 or informational use "was placed at the top of the flowchart, suggesting that instructors transmit content when they first use a CMS. CMS features for evaluating students or creating discussions are adopted much less often than transmitting content, so the flowchart suggests categories containing these features are adopted after instructors have transmitted content in a CMS. The lowest categories on the flowchart contain CMS features that instructors infrequently use, which are student surveys and computer based instruction. The flowchart suggests most instructors will use these features only after they have used features in the Level 2 categories. The lowest level in the flowchart suggests new features will be adopted when instructors identify learning needs that can be met with additional CMS features" (p. 169).

All these observations and arguments have in common that a basic usage level of specific technologies, is required to foster the adoption of more advanced types of technology use. Therefore, within the context of the present study about LMS usage, we expect informational use of the LMS to be use positively associated with communicational use.

H1: Informational use positively affects communicational use

Perceived usefulness, perceived ease of use and subjective norm

Perceived usefulness is defined by Davis (1989) as "the degree to which a person believes that using a particular system will enhance job performance" (p. 320). In most TAM-studies, perceived usefulness has been the strongest predictor for behavioral intention. King and He (2006) therefore conclude their meta-analysis with the statement: "if one could measure only one independent variable, perceived usefulness would clearly be the one to choose" (p. 746). But even if users think their performance will benefit from technology usage, they do not necessarily actively engage with the technology. Davis (1989) explains this as follows: "they may, at the same time, believe that the system is too hard to use and that the performance benefits of usage are outweighed by the effort of using the application" (p. 320). In this respect, the variable perceived ease of use plays a role. It refers to an individual's believe that using a system or technology is free of effort. The third variable in our study, subjective norm, refers to the social influence of important others (Ma et al., 2005). Though Davis (1989) did not include social influence as a direct determinant of behavioral intention, Venkatesh and Davis (2000) reconsidered this variable in the TAM2 model, especially in settings where a particular technology usage is mandatory. Van Raaij and Schepers (2008) refer in this context to LMS environments when they have to be used in order to complete the course. This reconfirms the position of subjective norm in the present study. The traditional TAM components in our model lead to four hypotheses.

H2a: Perceived usefulness positively affects informational use

H2b: Perceived ease of use positively affects informational use

H2c: Perceived ease of use positively affects perceived usefulness

H2d: Subjective norm positively affects perceived usefulness

Personal innovativeness towards IT

Personal innovativeness towards IT is defined as the willingness of an individual to try out any new information technology (Agarwal & Prasad, 1998). Van Raaij and Schepers (2008) regard personal innovativeness as "a form of openness to change" (p. 841). They concur with Schillewaert et al. (2005) that "being used to adapting to new systems and processes might reveal the usefulness and ease of use more quickly to an innovative person than to a non-innovative person" (p. 843). Lewis, Agarwal, and Sambamurthy (2003) add that available research consistently points at personal innovativeness towards IT as an important predictor of technology acceptance.

As reported by Schillewaert et al. (2005), it is not only possible to distinguish a direct relation between personal innovativeness and technology adoption, but also an indirect relation through perceived usefulness and perceived ease of use. They concluded that a person's predisposition towards technology plays an important role. They also stress that some people have a prejudice against technology. This is also observed in educational contexts, where this variable can help to

explain the non-adoption of LMS by 19% of teachers, despite an LMS being available at school (De Smet & Schellens, 2009). In this respect, we expect that a teacher with a higher level of technological innovativeness will more readily use an LMS, and this up to the communicational level.

H3a: Personal innovativeness towards IT positively affects communicational use

H3b: Personal innovativeness towards IT positively affects perceived ease of use

H3c: Personal innovativeness towards IT positively affects perceived usefulness

Internal ICT support

Sánchez and Hueros (2010) indicate that technical support is one of the most important factors in the acceptance of educational technology. Also Ngai, Poon, and Chan (2007) reported a strong - indirect - effect of technical support on attitude, thus underscoring the importance of user support and training on the perceptions of users and eventually their use of the system. This is confirmed by the significant and strong association between teacher perceptions of school-based ICT support and actual classroom use of ICT in the study of Tondeur, Van Keer, van Braak, and Valcke (2008). We can therefore assume that internal ICT support will influence the perceptions of the teachers and the use of the LMS.

H4a: Internal support towards ICT positively affects informational use

H4b: Internal support towards ICT positively affects subjective norm

Experience

Though experience is often mentioned as a mediating factor, Sun and Zhang (2006) stressed that there is a need for an operational definition of experience that fits particular professional knowledge domains. Building on their work, we conceptualize experience in this study as the number of years teachers have worked with an LMS.

According to King and He (2006), the level of experience is the best-studied variable in TAM, consistently reiterating the difference between inexperienced and experienced users. As a result, we assume that experienced teachers will use the LMS more for informational use than inexperienced teachers.

Malikowski et al. (2007) argued that instructors use an LMS to transmit information to students, but hardly use features that allow them to create interactive learning activities. They state that "this reflects an incremental approach in using CMS features because instructors are familiar with transmitting information—from experience in distributing syllabi, writing manuscripts, using PowerPoint presentations, or attaching files to e-mail messages" (p.152). Venkatesh et al. (2000) reasoned that as direct experience with technology increases overtime, individuals have a better assessment of the benefits and costs associated with the use of technology. Applying the latter to the present research context, we expect that the level of experience will influence perceived ease of use and the informational use of an LMS.

H5a: Experience positively affects perceived ease of use

H5b: Experience positively affects informational use

Burnham and Anderson (2002) argued, "a parsimonious model, representing a well-defended scientific hypothesis, aids in our understanding of the system of interest" (p. 438). When structural equation modeling is applied, Cheng (2001) added, "in order to achieve the goodness-of-fit indices and obtain the 'best fitting' model, unexpected relationships between indicators of different variables or between indicator and a non-underlying variable have to be minimized" (p. 651). Bringing together the available empirical and theoretical base in relation to the use of LMS, we can draw the following conceptual and parsimonious model.

Method

Participants

Teachers were recruited as participants in the study via their schools. About seventy-two schools were willing to participate, counting for data from 505 teachers (41% response rate). This teacher sample was closely studied and found to be representative for the population, considering the variables 'teaching levels in Flemish secondary education' (age level 12 to 18 years) and the type of secondary education (general, technical, and vocational). Respondents were given the option to fill out a paper and pencil version or an online version of the research instruments. Of the 505 questionnaires, 129 questionnaires were completed online, 376 were collected on paper. Post hoc, independent sample t-tests were used to check differences in answer patterns. No significant differences were found in response patterns between the two presentation formats.

All participating schools are situated in an urban area. Belgium, and the region of Flanders in particular, is one of the world's most urbanized countries in the world (United Nations World populations prospects, 2011). The sample consisted of 57.3% female respondents, which is close to the percentage (61.5%) in the population (Flemish Ministry of Education and Training, 2008). Teacher age range varied from 22 to 61 years, with an average age of 40 (SD = 10.5), teacher experience ranged from 1 to 42 years, with an average of 15 (SD = 10.8). We grouped participants based on the courses they teach and found out that 24% of them are language teachers (Dutch, French, English, German, Spanish, Latin, Greek etc.), 24% science teachers (math, biology, geography etc.), 18% reported teaching technical or vocational courses (electricity, haircut, hotel etc.) and 34% general courses (history, economy etc.).

Research instruments

A survey instrument was developed, consisting of two main sections. The first section focused on demographic (age and gender, coded 0 = female and 1 = male) and teacher related variables (such as number of years working as a teacher, grade, and teaching subject). The second section focused on the constructs as represented in the conceptual research model (Figure 1). Twelve items helped to determine the level of informational use and communicational LMS use. Items about document publishing, sending announcements, uploading or publishing exercises, receiving assignments, the agenda, student tracking, and the reservation module are linked to informational LMS-use. Items about the use of the assessment module, the chat environment, learning paths, a discussion forum and the wiki environment are linked to communicational LMS-use. Respondents were asked to indicate on a five point Likert scale to what extent they did actively use the particular LMS tool or functionality.

We adapted the four-item effort expectancy scale for perceived ease of use and the four-item performance expectancy for perceived usefulness of Venkatesh et al. (2003). For subjective norm, the original two-item scale based on Azjen and Fishbein (1980) is used. Personal innovativeness towards IT is assessed with the four-item scale from Agarwal and Prasad (1998). Internal ICT support is based on the four-item scale by Tondeur et al. (2008). All of these items are measured on a five-point Likert-scale, ranging from 'totally disagree' (1) to 'totally agree' (5). For all constructs, mean scores were calculated to evaluate the research model in figure 1.
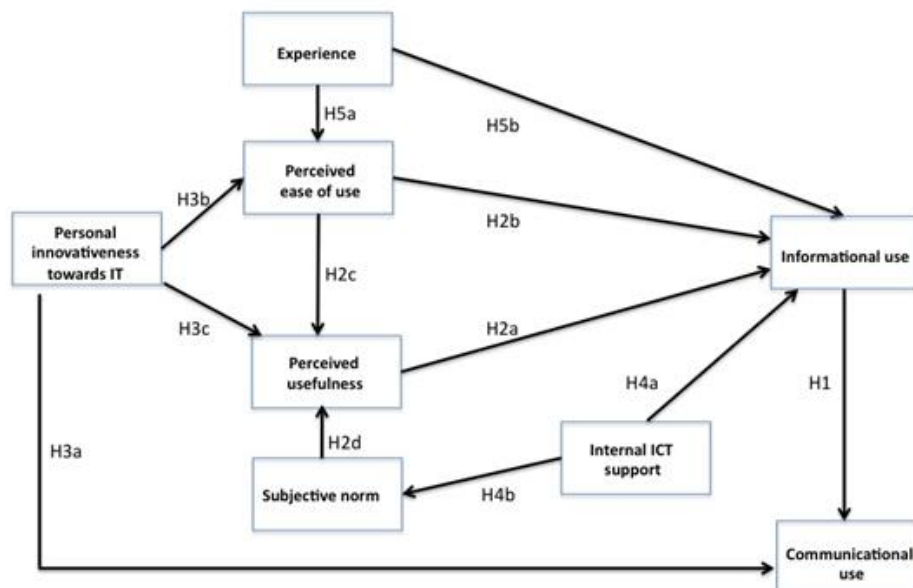

Figure 1. Theoretical model.

Results

Psychometric quality of the research instruments

To check the psychometric quality of the instrument section focusing on the identification of types of instructional usage of an LMS, a two-step validation procedure was adopted. The sample (N = 505) was divided randomly into two sub-samples to evaluate the construct validity. IBM SPSS Statistics 18 was used to conduct an exploratory factor analysis (EFA) on the data of the first sub-sample (n = 253), using Maximum Likelihood estimation with oblique rotation. The Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy was .84, exceeding the suggested threshold for factor analysis of .6 (Tabachnik & Fidell, 2007). The Bartlett's test of sphericity was – as required – significant at .001 level. The number of factors was determined by a parallel analysis (O'Connor, 2000) and an examination of the scree-plot. On the basis of a first EFA, a two-factor solution was found, but three items (student follow-up, the reservation module and the agenda) were deleted due to communality values exceeding the threshold. A second EFA was performed on the 9 remaining items. A two-factor solution emerged, accounting for 60.5% of the common variance among the items, with eigenvalues of 4.01 and 1.43.

As illustrated in Table 2, two substantially different constructs can be distinguished and are in line with the findings of Hamuy & Galaz (2010). Document publishing, sending announcements, upload or publish exercises and receive assignments can therefore be considered as indicators of an informational level in LMS usage. Assessment modules, chat, learning path, forum and wiki can be labeled as indicators of the communicational level in LMS usage.

Table 2.

Exploratory factor analysis of the dependent variable (9 remaining items)

	Factor	
	Informational use	Communicational use
Document publishing	**0.931**	-.0107
Sending announcements	**0.719**	-0.032
Upload or publish excercises	**0.582**	0.183
Receive assignments	**0.485**	0.250
Assessment modules	-0.080	**0.800**
Chat	-0.110	**0.718**
Learning path	0.162	**0.635**
Forum	0.141	**0.565**
Wiki	0.093	**0.535**

Next, AMOS 18 was used to perform a confirmatory factor analysis (CFA) on the data of the second sub-sample (n = 252) and building on the two-factor structure resulting from the EFA.

Error terms were not allowed to correlate. The following indices were calculated, taking into account criteria for the evaluation of goodness-of-fit indices (Byrne, 2001; Garson, 2009): Chi-square / degrees of freedom is less than 3 (2.11), the root mean square error of approximation (RMSEA) is higher than .05 (.07), but lower than .08, reflecting a reasonable fit. The comparative fit index or CFI (.97), the normed fit index or NFI (.94) and the Tucker-Lewis index or TLI (.94) reflect good fit values since they are close to .95. To conclude, on the base of the EFA and CFA, we can state that the instrument to determine instructional LMS use reflects good construct validity.

Construct validity was evaluated for the other variables measured with the instrument. Exploratory factor analysis (n = 253) using Maximum Likelihood estimation with oblique rotation was performed. The Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy is .86, exceeding the suggested threshold for factor analysis of .6 (Tabachnik & Fidell, 2007). The Bartlett's test of sphericity is – as required – significant at .001 level.The number of resulting factors is in line with the specific variables that was intended to be measured.

Table 3 summarizes the results of a reliability study (Cronbach's alpha). All values are close to .80, exceeding the threshold value (Nunnally, 1978). In addition, correlations between all variables are reported. A correlation matrix approach was applied (as illustrated in Table 3); most values are low among the different constructs. All mentioned values still suggest adequate validity of measurements.

Table 3.

Means, standard deviations, Cronbach's alpha (α) of all variables and their correlations

	Mean	S.D	α	1	2	3	4	5	6	7
1. PU	3.44	0.85	0.90	1						
2. PEOU	3.39	0.91	0.88	0.39**	1					
3. SN	3.10	0.99	0.93	**0.41****	0.18**	1				
4. PIIT	3.03	0.99	0.90	0.26**	**0.40****	0.05	1			
5. ICTs	3.01	0.77	0.89	0.15**	0.15**	0.20**	0.12**	1		
6. Informational use	3.00	0.26	0.83	**0.42****	**0.46****	0.20**	0.23**	0.21**	1	
7. Communicational use	1.69	0.76	0.78	0.30**	0.24**	0.15**	0.23**	0.23**	**0.52****	1

Note. PU (perceived usefulness), PEOU (perceived ease of use), SN (subjective norm), PIIT (personal innovativeness towards IT) and ICTs (internal ICT support).
** Correlation is significant at the .01 level

Path analysis research model

As stated earlier, the hypothetical relationships between the variables were tested in AMOS 18. A correlation matrix (pairwise deletion) was used as input to account for missing values. The following fit indices were obtained. Chi-square /degree of freedom is 3.97, the root mean square error of approximation (RMSEA) is .078, suggesting a reasonable fit. The comparative fit index or CFI (.94), the normed fit index or NFI (.92) and the Tucker-Lewis index or TLI (.89) have values close to .9 or approach the benchmark of .95. All common goodness-of-fit indexes, exceeded or approached their respective common acceptance levels, suggesting that the research model exhibited an acceptable fit with the data. Properties of the causal paths, including standardized path coefficients and p-values are presented in Figure 2.
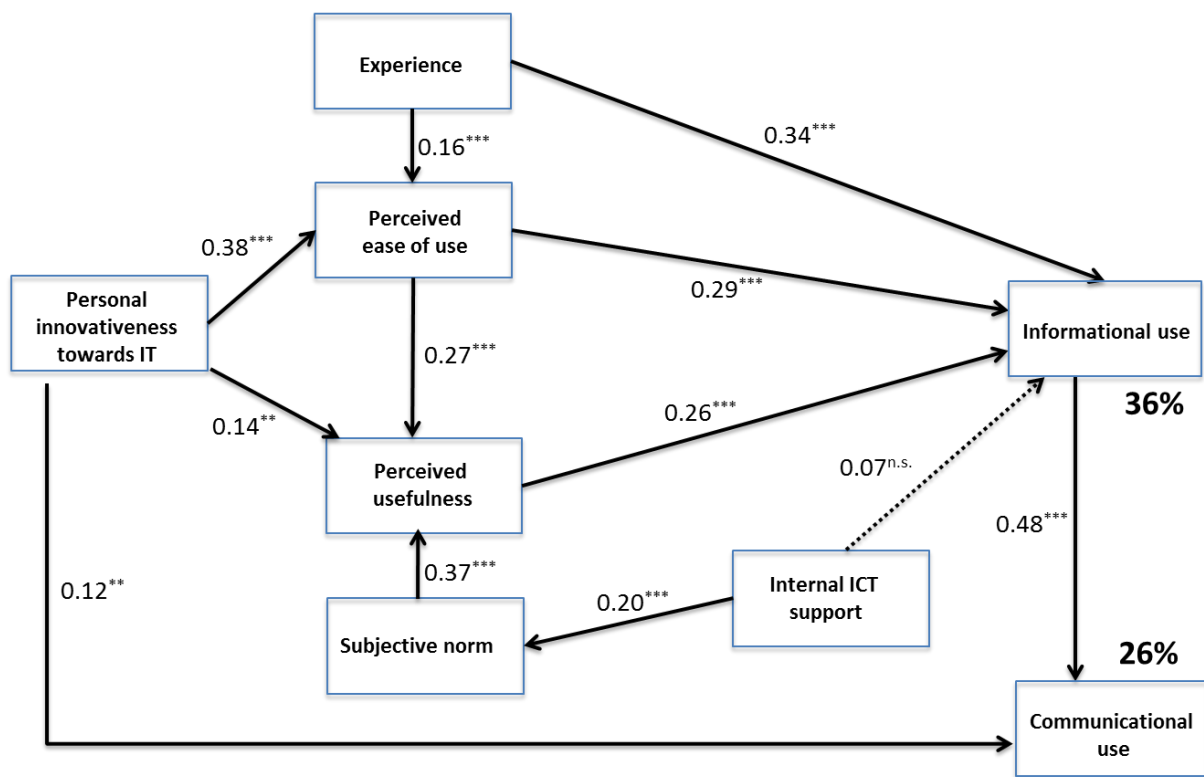

Figure 2. Model testing results

Note. n.s. = not significant, * *p* < .05,***p* < .01, *** *p* < .001

Hypothesis testing

Figure 2 also provides an overview of the path coefficients. As to the assumption that informational use is positively associated with communicational use (H1), this hypothesis was supported (β = .48, *p* <.001).

The traditional TAM components appeared in four hypotheses. Perceived usefulness has a positive significant association with informational use (H2, β = .26, p <.001). Perceived ease of use affects in a significant and positive way informational use (H3, β = .29, p <.001) and perceived usefulness (H4, β = .27, p <.001). Subjective norm is found to be a significant factor in determining perceived usefulness (H5, β = .37, p <.001). In line with other TAM studies, all hypotheses constituting the TAM2-framework (H2, H3, H4 and H5) are confirmed.

The findings show that personal innovativeness in the domain of ICT has a direct positive association with perceived ease of use (H7, β = .38, p <.001) and with perceived usefulness (H8, β = .14, p <.01). The relationship with communicational use is significant but rather weak (H6, β = .12, p <.01).

Hypotheses H9 and H10 postulated the impact of internal ICT support on informational use and subjective norm. The analysis results show that internal ICT support has a positive significant association with subjective norm (H10, β = .20, p <.001), but also that it does not significantly affect informational use (H9, β = .07, p = .068).

Experience has a significant relationship with perceived ease of use (H11, β = .16, p <.001) and with informational use (H12, β = .34, p <.001).

The entire model is able to explain 36% of the variance in informational use and 26% of the variance in communicational use.

The modification indices further indicated that an additional relation - from internal ICT support to communicational use - could further improve the model. Additional path analysis showed that the standardized regression weight was .12 (p < .01). The new model explained 27% of the variance in communicational use.

Discussion and implications

The present study aimed at identifying a number of significant factors of types of LMS usage in secondary school teachers. The study contributes to the literature in a number of ways. First, the instructional use of LMS by secondary school teachers has been further explored and refined. Second, the study focused on the acceptance of the LMS by secondary school teachers, an understudied group. Further, the operationalisation of instructional use of an LMS into informational use and communicational use appeared to be valid. The research model is able to explain 36% of the variance in informational use and 26% of the variance in communicational use. As hypothesized, informational use seems to be positively associated with communicational use.

Furthermore we could successfully build on perceived usefulness, perceived ease of use and subjective norm as important factors in the TAM2-framework. Both perceived ease of use and perceived usefulness were found to be strongly related to informational use. This means that in order for a secondary school teacher to use his LMS in an informational way, the usefulness and the ease of use of the LMS will be both taken into consideration. However, since perceived ease of use and subjective norm significantly affect perceived usefulness, we can additionally postulate that the ease of use of the LMS should be a critical initial variable, followed next by teachers' perception of the system's performance.

Another interesting result is the statistical insignificance of the relation from internal ICT support to informational use, and the significant association from internal ICT support with subjective norm. This finding implies that supporting teachers at the school level will not directly influence personal use, but especially impact the opinion of important others. More important, as also indicated by Tondeur et al. (2008), the impact of internal (school) ICT support suggests that school level variables are important to understand technology acceptation. The adoption of the variable internal ICT support makes the TAM model congruent with the real – school - world setting and conditions as requested by Sun and Zhang (2006) and Ong et al. (2003). Also important is the significant relationship between personal innovativeness and perceived ease of use. This suggests that innovative teachers are more easily convinced about the ease of use of the LMS. On the other hand, the impact of innovativeness on usefulness was lower, meaning that being innovative does not automatically result in a positive belief about a system's performance. This is also confirmed by the impact of personal innovativeness towards IT on communicational use. Being innovative is clearly not enough to start using an LMS for communicational use.

Based on the importance of the teacher's perception of the ease of use of their LMS and the availability of support, school managers or LMS coordinators can consider the following practical recommendations. Introduction sessions can be considered and manuals provided. If applicable, a decent translation of the LMS to the native language of the teacher and clarification on specific design characteristics should be foreseen. Some teachers aren't familiar with functionalities like the wiki or the learning path module. Best practices, continuous training and

easy access to support will definitely be valuable for the teacher and might be that extra little thing to get them inspired.

Conclusion and limitations

The purpose of this paper was twofold: 1) developing a better understanding of secondary school teacher acceptation of a LMS and 2) studying the way this group of teachers actually uses an LMS in their instructional setting. Though the results discussed above have clearly helped to attain our research goals, a number of limitations are to be considered.

First, instead of reported use of an LMS, we expect that using log files could lead to more accurate LMS related data. However this was not feasible practically in the current study, given the number of respondents and the difficulties in getting access to log files. Second, our research validates the categorization of LMS interactions as defined by Hamuy & Galaz (2010). However, additional LMS functionalities, such as student tracking, the reservation module and the agenda had to be removed during the factor analysis procedure. Future research should continue to focus on the refining of LMS usage categories. Third, our analysis was based on a cross-sectional design, whereas a longitudinal study would have provided more support to generalize the findings. Fourth, the path analysis indicated an acceptable yet not perfect fit between the data and the hypothesized model, indicating there is potential to improve the model with additional relations and variables. Especially the role of internal ICT support deserves further attention, as the modification indices indicated a positive association with communicational use. Further research could also focus on identifying additional variables to explain the adoption and implementation of communicational use. The latter could be for instance linked to beliefs of teachers about the types of learning strategies that are linked to the adoption of these LMS functionalities. Tondeur et al. (2008) could link specific teacher beliefs to specific types of ICT usage. The same could be done in the case of LMS adoption. Fifth, to determine the particular relation between informational use of an LMS and communicational use (as suggested in our model), an alternative approach could build on distinguishing subgroups of teachers; teacher with a low versus a high level of informational use and apply a path-analysis by contrasting both groups.

Nevertheless, the present study resulted in an acceptable structural model about the relationships between critical variables describing LMS adoption and usage. Moreover, this - large-scale - study involving secondary school teachers, focused on an understudied group of LMS users within educational research.

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3 The design and implementation of learning paths in a learning management system

This chapter is based on:

Chapter 3:
The design and implementation of learning paths in a learning management system

Abstract

Learning paths have the potential to play an important role in the way educators serve their learners. Empirical research about learning paths is scarce, particularly in a secondary education setting. The present quasi-experimental study took place in the context of a biology course involving 360 secondary school students. A 2 x 2 factorial research design was adopted. Learners were engaged in learning activities in a learning path. These learning activities (1) differed in design and (2) were either undertaken individually or collaboratively. Gender was considered as a critical moderator given the focus on science learning. All learning paths were developed on the basis of visual representations, but in the experimental design conditions, learners worked with learning paths designed according to Mayer's multimedia guidelines (2003). Multilevel analyses were applied to study the impact on learning outcomes according to the design of learning paths, the individual/collaborative setting, and gender. The study provides empirical evidence that both the design and the group setting (collaborative versus individual) have an impact on learning outcomes. Although there was no main effect, several significant interaction effects with gender were found. The results are helpful to direct research about the design and implementation of learning paths in a secondary school setting and underpin the relevance of representation modes in science learning.

Introduction

Earlier research by De Smet, Bourgonjon, De Wever, Schellens, and Valcke (2012) studied the rationale behind the technology acceptance of learning management systems (LMS) by secondary school teachers and also investigated the particular instructional use of LMS within this group of teachers. They found the 'informational use of the LMS' or content published by the users (as defined by Hamuy & Galaz, 2010) was positively associated with 'communicational use,' or all processes that foster the exchange of these contents, between LMS users. In other words, a basic usage level (e.g., document publishing or sending announcements) seems to be required before more advanced LMS functionalities can be adopted, such as a wiki (collaborative writing), a forum (moderated discussions) or learning paths (technology-enhanced road map).

De Smet and Schellens (2009) observed that from 376 Flemish secondary school teachers, only 10% actively used the learning path module. This low adoption level suggests that teachers do not know how to design and implement these learning paths. As a result, this study will focus on how learning paths could be appropriately designed and implemented.

Most literature on learning paths can be found within research for technology-enabled learning that studies algorithms for computer-adaptive systems (Capuano et al., 2009; Wong & Looi, 2012). Within this article, a 'learning path' refers to the LMS functionality to order a number of learning objects in such a way that they result in a road map for learners. Within a learning path, learning steps are pre-structured in a general way (as a navigation map or a table of contents) or in a very specific sequenced way (e.g., 'complete first step 1 before moving on to step 2'). Learning paths can be created with authoring tools (e.g., eXe, Xerte, Udutu) or programmed by software developers. Central to the design of a learning path are the building blocks: the learning objects. Although the concept of 'learning objects' is widely used, its definition is not always clear. According to Wiley (2000), the most cited definition of learning objects comes from the Learning Technology Standards Committee (also known as IEEE, 2005): "any entity, digital or non-digital, which can be used, re-used or referenced during technology supported learning" (p.4). In his review of definitions of learning objects, Kim (2009) concluded that most definitions include terms such as 'learning,' 'instructional,' 'pedagogical,' or 'educational.' In this article, we put forward the definition by Kay and Knaack (2007), who defined learning objects as "interactive web-based tools that support the learning of specific concepts by enhancing, amplifying, and/or guiding the cognitive processes of learners" (p. 6).

Learning objects have the potential to play an important role in the way teachers teach and learners learn. However, empirical research about learning objects is scarce, particularly in secondary education (Kay & Knaack, 2008). Cochrane (2005) found relatively little research reporting design principles for learning objects. Dalziel (2003) argued that e-learning usually has "a well-developed approach to the creation and sequencing of content-based, single learner, self-paced learning objects," but added "there is little understanding of how to create sequences of learning activities" (p. 593). In addition, he emphasizes there is hardly any research addressing how to support learners with learning objects in a structured, collaborative environment. Given the lack of empirical research focusing on how learning paths should be designed, presented and implemented, and the lack of impact studies on student performance (Kay & Knaack, 2005; Nurmi & Jaakkola, 2006), we concentrated in this study on the impact of learning with learning paths that vary (1) in their design and (2) in the way they are studied, individually or collaboratively. In the next sections, we first present the theoretical basis underpinning design decisions for learning paths and the rationale in relation to collaborative versus individual study of the learning paths. Since our study is set up in the domain of science learning, we also focus on gender, a key variable in science education research.

Theoretical and empirical framework

Visual representations

Learning paths can differ in the way they are visually represented. The value of visual representations in the design of learning paths can theoretically be linked to Cognitive Load Theory (Sweller, 1988, 1994; Sweller, van Merriënboer & Paas, 1998; van Merriënboer & Sweller, 2005) and the Cognitive Theory of Multimedia Learning (Mayer, 2001, 2003, 2005). Cognitive Load Theory (CLT) is an instructional theory that focuses on the human cognitive architecture and its consequences for the design of instruction and learning materials. The Cognitive Theory of Multimedia Learning (CTML) reiterates CLT's cognitive architecture but looks even more explicitly at design principles for multimedia learning.

Cognitive Load Theory

Cognitive Load Theory is based on the assumption that the processing capacity of working memory (WM) of individual learners is limited, which is in contrast to an unlimited long-term memory (LTM). When new information is not well structured, too abundant, or not well represented, it will invoke extraneous cognitive load (see below) that will hinder the processing of new information, resulting in less successful storage in LTM (Baddeley, 1986). CLT also builds on the assumption that information is organized into schemas within WM, and are subsequently stored and retrieved more easily in/from LTM (Sweller, van Merriënboer & Paas, 1998). A schema is a cognitive structure that connects a large amount of information that can be processed as a single unit in working memory and stored in long-term memory. One frequently used example is that of a chess grand master who uses schemas to categorize board pieces and board moves into patterns. Information processing can occur automatically or consciously (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Automatic processing occurs after extensive practice and results in freeing up working memory, while conscious processing occurs in working memory itself and requires memory resources, thus invoking cognitive load. Therefore, a novice chess player who has few such schema available in LTM will need more time to execute a chess move than a professional player. In order to foster learning, schema construction is important, as it leaves working memory open for other tasks and stores information in LTM.

CLT distinguishes three types of cognitive load: intrinsic, extraneous, and germane cognitive load (Sweller et al., 1998). Intrinsic cognitive load is dependent on the intrinsic complexity of the information (number of elements and the interrelations between them). Germane cognitive load refers to the effort required to construct schemas. Extraneous cognitive load is the effort required to process information in view of schema construction. The latter is strongly dependent on the way information is represented.

CLT theory challenges instructional designers to design learning material that results in meaningful learning but does not put too heavy a burden on working memory (Sweller, 1999;

van Merriënboer, 1997). Paas, Tuovinen, Tabbers, and Van Gerven (2003) state, "because intrinsic load, extraneous load, and germane load are additive, it is important to realize that the sum of intrinsic, extraneous, and germane cognitive load, should stay within working memory limits" (p.65). Given the fact that intrinsic load is intrinsic to the task, and germane cognitive load is required for schema construction, instructional designers should control extraneous load. Different techniques have been researched to handle extraneous cognitive load, among others, the Cognitive Theory of Multimedia Learning (Mayer, 2001, 2003, 2005).

Cognitive Theory of Multimedia Learning

Instructional designers recognized the need for learning materials that are sensitive to cognitive load (Mayer & Moreno, 2003). A lot of research has been done based on the Cognitive Theory of Multimedia Learning (CTML), as postulated by Mayer (2001, 2003, 2005). This theory represents a framework to direct instructional design of multimedia materials and results in the definition of practical guidelines to design multimedia learning materials.

CTML is based on three assumptions (Mayer, 2003): the dual channel assumption, the limited capacity assumption, and the active learning assumption. The dual channel assumption is derived from the research of Paivio (1978, 1991) and Baddeley (1992). Central to this assumption is that two separate information processing systems are active to process visual (e.g., text, images) and verbal (audio) representations. The limited capacity assumption also builds on the work of Baddeley (1992) and Baddeley, Gathercole and Papagno (1998). It states the amount of processing that can take place within the visual and auditory processing channel is limited. The active learning assumption is built on Wittrock's (1989) generative learning theory and implies the learner is actively engaged in processing information and mentally organizes it. Cognitive processes involved include selecting (visual/audio), organizing (mental representation), and integrating (visual, audio, and prior knowledge). In order to study the impact of learning path design, we build in the present study on CTML to differentiate between two learning paths, differing in the degree of elaboration and structure.

Collaborative learning

In this article, the term 'collaborative learning' refers to the engagement of all participants in solving a problem together (Roschelle & Teasley, 1995). Akkerman et al. (2007), building on the work of Valsiner and Van der Veer (2000), present both a cognitive and a socio-cultural view when focusing on group cognition. Within the cognitive perspective, the subject of learning is the individual who constructs knowledge about the surrounding world. Following the socio-cultural perspective, the learner is seen as a participant of a social entity where knowledge results from interaction and social activity. Akkerman et al. (2007) add that, within the cognitive view, the social aspect is not denied but rather "understood through its residence in the mind of the individual" (p.42).

Putting learners in a group does not guarantee spontaneous collaboration (Cohen, 1994) or effective learning behavior (Soller, 2001). As a result, instructional support is provided to scaffold or script the collaborative learning process (Kollar, Fischer & Hesse, 2006). Given the focus on learning management systems in the present article, the design of collaborative learning can strongly build on research in the field of Computer Supported Collaborative Learning (CSCL). Kollar, Fischer & Hesse (2006) put forward five minimum characteristics of scripting in a CSCL setting: scripts must 1) contain an objective, 2) engage learning activities, 3) sequence all required actions, 4) specify and distribute roles, and 5) contain a type of representation in which instructions are presented to the learners. In this research, we used teacher scenarios (see below) that were based on scripts.

Adopting collaborative learning in the context of learning paths, can – from a theoretical perspective – also be linked to cognitive load theory. Kirschner, Paas, and Kirschner (2009a) found that groups can be considered information-processing systems containing multiple working memories, and as such, create a collective working space where cognitive load can be divided among the learners. In this view, groups are favored against individuals who can only rely on their individual working memory. Furthermore, when the group work is well structured (e.g., building on strongly elaborated and structured learning objects in the learning path), it reduces extraneous cognitive load and helps learners maximize cognitive processes that result in schema construction (Sweller, Van Merrienboer, & Paas, 1998), and thus, higher learning outcomes.

Science education and gender

The present study takes place within the setting of STEM education (science, technology, engineering, and mathematics). Although STEM education leads to good jobs and a higher standard of living, today's youth seem to have little interest in science as a possible career path (European Commission, 2004, 2006; Organisation for Economic Co-operation and Development [OECD], 2007, 2008; U.S. Department of Education, 2007; National Governors Association, 2007). In addition, there is a clear gender gap in the STEM field. Several studies (European Commission, 2004, 2012) reveal that females are underrepresented in science careers. This comes in sharp contrast to the observation that girls are more successful at school, as they obtain higher grades and are less likely than boys to repeat a year (European Commission, 2006). In a recent publication, the European Commission (2012) presented the following reasons for this gender gap: stereotypes found in children's books and school manuals, gendered attitudes of teachers, gendered advice and guidance on courses to be followed, and different parental expectations regarding the future of girls and boys.

Research about gender differences does not always present a consistent picture. PISA 2012 (OECD, 2013) showed different levels of performance in science, reading, and mathematics between males and females, although differences were significantly larger within, rather than between, genders. Nevertheless, significant gender differences were observed for reading (in favor of girls) and mathematics (in favor of boys). They also found that for mathematics, girls are

under-represented among the highest achievers in most countries and economies, and males have higher perceptions about their science abilities as compared to females. This is in line with research from Eclles (1994) and Lubinski and Benbow (2006), which stated that women are less likely to enter occupations linked to mathematics and physical sciences because they have less confidence in their abilities and place less subjective values on these fields compared to other occupations. Furthermore, Eccles (1994) argued that girls rate social values high and prefer to study academic subjects that have social implications, which, in the long term, enable them to do something worthwhile for society.

Learning outcomes based on gender

We believe the main conditions under study (i.e., design decisions and the group setting) influence learning outcomes based on gender. When studying design conditions, we refer to Super and Bachrach (1957), as well as more recent follow-up research by Wai, Lubinski, and Camilla (2009), which focused on the critical role of spatial ability within STEM-education. The construct spatial ability was defined by Lohman (1994) as "the ability to generate, retain, retrieve, and transform well-structured visual images" (p. 1000). Mayer and Sims (1994) found evidence that high-spatial learners had to dedicate fewer cognitive resources to build a representational connection between visual and verbal material, thus leaving more room for other processes. From their longitudinal findings, Wai, Lubinski and Benbow (2009) concluded that high levels of spatial visualization have a robust and highly relevant influence in approaching STEM domains. Ceci and Williams (2010) added that males excel in spatial ability and underline the fact that in large meta-analyses, the effect size for spatial ability is substantial: .50 to .75 for male superiority. As the second version of our learning path is optimized with Mayer's guidelines (2003), leading to a better elaborated and structured course, we can postulate that this optimized version will offer better spatial visualization.

When researching group setting, we can build on group diversity literature. Harrison and Klein (2007) describe group or unit diversity as "the distribution of differences among the members of a unit with respect to a common attribute X" (p. 1200). They differentiate diversity as: separation (differences in opinion among members), variety (differences in knowledge and/or experience) and disparity (differences in status and/or power), and concluded that only variety has a positive impact on group effectiveness. As a result, gender diversity can be conceptualized as gender separation, gender variety, or gender disparity. Extending the work of Harrison and Klein (2007), Curşeu, Schruijer and Boroş (2007) and Curşeu and Sari (2013) found gender variety indeed has a positive outcome on group cognitive complexity, and mixed-gender groups achieve better results. Moreover, Curşeu and Sari (2013) stress that "the core argument in this line of research is that gender variety increases the pool of cognitive resources of groups because men and women have qualitatively different life experiences, therefore likely to have different task-related knowledge structures (Curşeu, Schruijer, & Boros, 2007; Rogelberg & Rumery, 1996)" (p. 1).

Slotta and Linn (2009) found web-based collaborative inquiry seems to be helpful in developing and maintaining positive attitudes towards science and science instruction. In a recent study, Raes, Schellens & De Wever (2014) found that low achievers, and more specifically, low-achieving girls, benefited from this type of intervention, especially with respect to the ability to participate in small group discussions.

On the basis of the group diversity literature and the positive impact that web-based collaborative inquiry has on girls, we expect that girls will benefit from working collaboratively.

Research design

Research question and research hypotheses

The main research question directing this study is whether additional investment in the design and implementation of learning paths will have a beneficial impact on learning outcomes. Gender is considered as a critical moderator given the focus on science learning.

Building on the theoretical framework of CTL and CTML, we put forward the first hypothesis (H1): Students studying a learning path, optimized with Mayer's (2003) guidelines in mind, will attain significantly higher learning outcomes as compared to students studying a basic learning path with multimedia learning objects.

Building on the CSCL framework, we put forward the second hypothesis (H2): Learners studying the learning path collaboratively will attain significantly higher learning outcomes as compared to students studying the learning path individually.

Considering the empirical data in relation to gender and STEM, we put forward a third, twofold hypothesis. Given the critical role of spatial ability, we expect (H3a) a significant interaction effect with respect to gender, in favor of males, when studying the learning path optimized with Mayer's guidelines (2003). In view of the group diversity literature and the positive impact web-based collaborative inquiry has on girls, we expect (H3b) a significant interaction effect with respect to gender, in favor of females, when studying the learning path collaboratively.

Participants

Secondary education in Flanders comprises six consecutive years of study, starting at the age of 12. We selected six secondary education schools in collaboration with a GO! staff member. GO! is one of the three dominant governing bodies that sets up schools in Flanders, the Dutch speaking area of Belgium. GO! schools comprise 15,27% of secondary school education in Flanders. Governing bodies have considerable autonomy to, among other things, develop school curriculum, recruit staff, choice of teaching methods, etc. As a consequence, the curriculum in the selected schools and classes is largely comparable. All participating schools are situated in

urban areas, as Belgium, and Flanders in particular, is one of the world's most urbanized countries (United Nations World Populations Prospects, 2011).

All biology teachers (N = 8; 3 males, 5 females) teaching in the third grade of each of the six schools were willing to participate in the study. Twenty-nine different classes were selected at random to participate in the study. All students enrolled in these 9th grade classes (N= 360; 167 males and 193 females) participated in all consecutive activities during the study. Students were, on average, 15 years old (89,4%). Figure 1 shows the participant flow chart.

Prior to the study, informed consent to use the data for research purposes was obtained through the different school teachers.
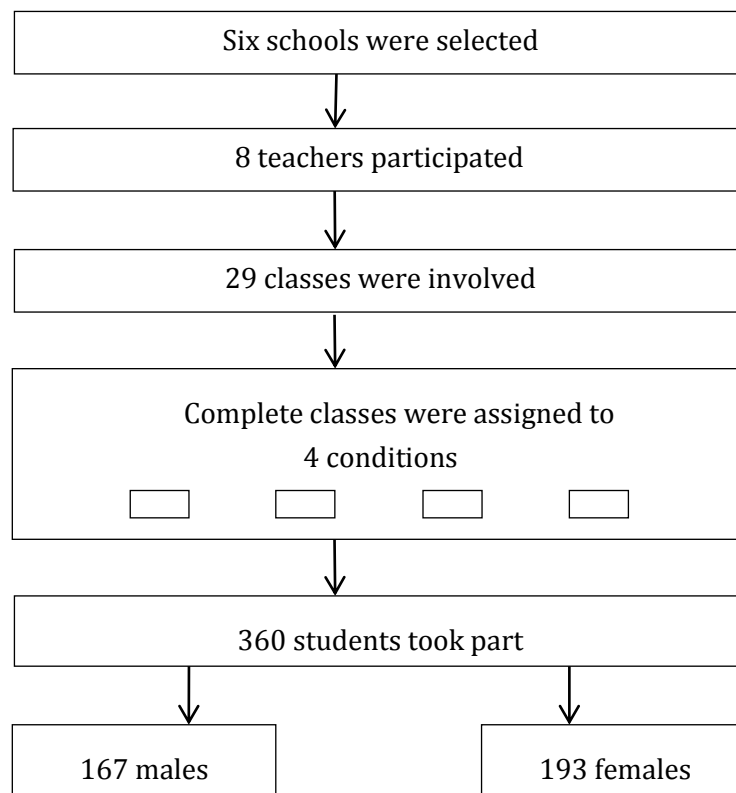

Figure 1. Participant flow chart.

The biology learning materials: Two versions of the 'Bacteria' learning path

In the present study, learning paths were developed using 'eXe learning,' an open-source authoring tool. Resources authored in eXe can be exported as a website or imported in any SCORM (Sharable Content Object Reference Model) compliant Learning Management System. This gives teachers the opportunity to open learning paths via a browser (online or offline) or to integrate these learning paths within their school LMS.

From the biology curriculum, the topic 'bacteria collection and growth' was selected in view of developing new learning materials. Two recently graduated biology teachers created learning materials following the official GO! biology curriculum. Next, these materials were reviewed and modified by 18 pre-service teachers majoring in biology under the supervision of their lecturer.

A first version of a learning path was elaborated, consisting of multimedia learning objects that build on text, schemes, pictures, and web-based exercises (see Figure 2). A second version of the same learning path was developed by applying Mayer's multimedia guidelines (2003). Based on the handbook by Clark and Mayer (2007), learning objects in the second version of the learning path were optimized by applying, for example, the multimedia principle (adoption of both audio and graphs), the contiguity principle (alignment of the text and the corresponding graphics), the redundancy principle (explanations next to visuals were either with audio or text, not both), and the coherence principle (no extra interesting materials were added). The active learning assumption (Wittrock, 1989, Mayer, 2003) stresses the learning material should have a coherent structure and provide guidance to the learner on how to build knowledge structures. As a result, advanced organizers were included in the optimized learning path in order to help organize unfamiliar content (Ausubel, 1960, 1968).

For reading purposes, we will refer to the first version of the learning path as the 'TSPW learning path' (Text, Schemes, Pictures and Web-based exercises) and to the second version as the 'MGL learning path' (Mayer GuideLines).

Rijk	moneren	protisten	fungi (zwammen)	planten	dieren
Celtype					
complexiteit	eencellig	(meestal) eencellig	meercellig	meercellig	meercellig
beweegbaarheid	soms	soms	nee	nee	ja
voedingswijze	autotroof of heterotroof	meestal heterotroof	heterotroof	autotroof	heterotroof
bladgroenkorrels	soms	nee	nee	ja	nee

levende wezens

In de 17e eeuw werd door Antonie van Leeuwenhoek een eerste microscoop gebouwd. Daarmee zag hij kleine (bewegende) organismen in regenwater en in tandplak, die organismen noemen we nu bacteriën.

Bacteriën zijn net zoals ons levende wezens.

In de eerste graad leerde je al wat levende wezens zijn en hoe ze ingedeeld worden in 5 rijken.

Activiteit

Ken je nog de kenmerken van levende wezens?
Weet je nog hoe de levende wezens ingedeeld worden?

Maak de oefeningen

- wat zijn bacteriën 1
- wat zijn bacteriën 2
- wat zijn bacteriën 3

in de oefeningen module.

Figure 2. The uppermost image depicts an advanced organizer (Ausubel) on bacteria classification that was offered to all students following a MGL learning path before navigating to the rehearsal bacteria classification exercises (the image at the bottom). Students following a TSPW learning path were only exposed to the rehearsal bacteria classification exercises. No other information on the subject was given to these learners.

Individual versus collaborative study of the learning paths

Along with a better multimedia elaboration of the learning path, we also studied the impact of the group setting. As defined by Kollar, Fischer and Hesse (2006), and as applied within this research, scripts contain several components, including a learning objective and a type of representation, in which instructions are presented to the learners. Scripts also engage learning activities and sequence all required actions.

We chose to implement scripts into teacher scenarios (see Figure 5 in Appendix) for two reasons. First, Flemish teachers are used to working with these scenarios on a daily basis. Pre-service teachers and in-service teachers use lesson preparation scenarios as part of their (sometimes obligatory) daily work routine. We used existing lesson preparation templates to create our teacher scenarios. Second, we wanted to guarantee the comparable nature of the

activities under all research conditions. The collaboration scenarios did not result in differences in the content of what was studied about bacteria; they differed in the way students organized, shared, and carried out their work to guarantee that students – in whatever research condition – received the same learning opportunities and to monitor the way students followed the particular learning path.

Research instruments: Learning performance

Students were offered knowledge tests at three separate moments: a pre-test, a post-test (immediately after completion of the learning path), and a retention test (one month after completion of the learning path). Each test consisted of 20 multiple choice and true/false questions. The study took, on average, between seven and nine weeks to be completed. However, since teachers were not able to refrain from monthly evaluation between the post-test and the retention test, we decided to focus on pre-/post-test differences in our study. Retention test scores are mentioned in Table 4; however, readers should keep in mind that these could be influenced by intermediate tests not taken into account in the present study.

All test items were created by two recently graduated biology teachers based on the official GO! biology curriculum. Six biology teachers tested all items within their classes. Based on the analysis of these tests and the teachers' item evaluation, some items were discarded and the remaining items were divided into three balanced tests (one test for each moment). Figure 3 shows how knowledge tests were created.

Item analysis was conducted to improve the quality and accuracy of the true/false items. A combination of item difficulty (p-value) and item discrimination (PBS or Point-Biserial correlation) was taken into account. Items with P-values above .90 and PBS-values near or less than zero were removed from the tests (Division of Instructional Innovation and Assessment, University of Texas at Austin, 2007). As a result, eight items were omitted from each test.
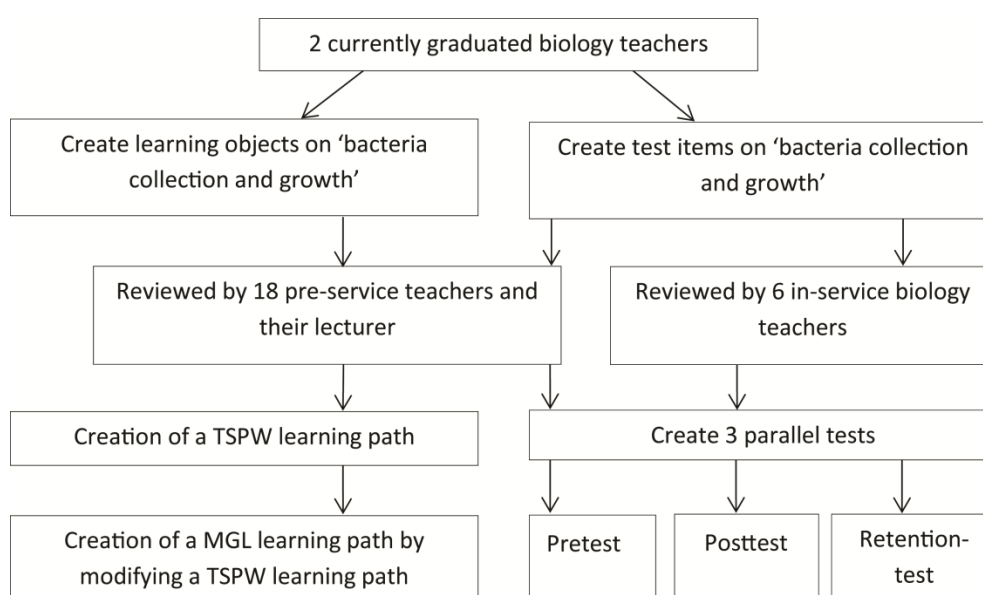
Figure 3. Creation process of the learning paths and the knowledge tests.

Procedure

The researcher visited all teachers and gave a one-hour introduction. We briefed teachers on all the aspects of the research process. Other topics discussed included, amongst others, the proposed time schedule and technical information concerning learning paths within the Learning Management System. Complete classes (N = 29) were assigned to the four different conditions (see Table 1). It was mandatory that all lessons took place in computer classes.

As can be observed in Table 1, we did not reach a balanced number of students across all conditions. Two teachers assigned to the collaborative condition of the MGL learning path had to cancel their participation. Given the last-minute character of these events and the unfortunate timing in the middle of a semester, we were not able to recruit new teachers nor to redistribute the teachers over conditions.

Depending on the condition they were assigned to, all teachers received a digital (USB-stick) and/or a paper version of the following material: a research guideline, a comprehensive teacher scenario, the proposed time schedule, and two versions of the learning path (HTML and SCORM). At the same time, we provided a box containing paper versions of all the knowledge tests. We also sent teachers an e-mail address and telephone number by which they could contact three researchers. Only a few minor technical questions emerged.

Table 1.
Number of participants across conditions.

	IndTSPW	ColTSPW	IndMGL	ColMGL
Males	59	63	37	8
Females	54	71	50	18
Total	113	134	87	26

Note: Ind = individual, Col = collaborative, TSPW = Text, Schemes, Pictures and Web-based exercises learning path, and MGL = Mayer GuideLines learning path.

Statistical analysis

Our data have a clearly hierarchical structure (i.e., students in classes from different schools were offered knowledge tests at three separate moments). This leads to the conclusion that individual observations are not completely independent given the selection processes, common history, and experiences students share (Hox, 1994). Knowledge scores from students in the same classes might be dependent, and thus break the assumptions of a simple regression analysis. By doing so, we would ignore school-level and class-level inferences and focus only on individual learning outcomes. In this respect, Multilevel Modeling is suggested as an alternative and adequate statistical approach (Diez-Roux, 2000, Nezlek, 2008), and most certainly in the

case of repeated measures (Goldstein, 2003). Within multilevel analysis, the hierarchical nesting, dependency, unit of analysis, standard errors, confidence intervals, and significance tests are handled correctly (Goldstein, 1995) and, in general, even more conservative than a traditional regression analysis where the presence of clustering is ignored (Goldstein, 2003).

Following Van Der Leeden (1998), we consider repeated measures as a hierarchical structure where measurements are nested within individuals. Consequently, our knowledge tests are defined as the first level, students as the second level, classes as the third level, and schools as the fourth level. We used MLwiN software (Centre for Multilevel Modelling, University of Bristol) to analyze the hierarchical data (Nezlek, 2008, Rasbash, Steele, Browne, & Goldstein, 2009).

We followed a two-step procedure to analyze the effects of three independent variables (design decisions, group setting and gender) on the dependent variables (learning outcomes). The models built following this procedure are presented in Table 4 (in appendix). First, we created a four-level conceptual null model (Table 4, Model 0) to serve as a baseline model. This unconditional null model (without any predictor variables) provides the overall pre-test, post-test, and retention scores across all students, classes, and schools. The second step concerned the input of the three main explanatory variables (visual representation, group setting, and gender) in the fixed part of the model and allowed cross-level interactions between student, class, and school characteristics. This resulted in Model 1 (Table 4).

Results

Model building

The models built following the two-step procedure are presented in Table 4 (in appendix).

Given our repeated measures approach, the conceptual unconditional null model (Table 4, Model 0) predicts the overall pre-test (M = the intercept, or 57.18 out of 100), post-test (M = 64.49 = 57.18 + 7.31), and retention test scores (M = 71.93 = 57.18 + 14.75) across all students, classes, and schools. Thus, in general, without taking into account visual representation, collaboration mode, and gender but controlling for the nested data structure, students score significantly higher on the post- and retention test as compared to the pre-test.

This null model also results in four variance estimates, as shown in the random part of the model: one for school level, one for class level, one for student level, and one for the measurement occasion. The variance in scores within this null model on the four levels are, except for the school level, significantly different from zero and significant at the $p <.001$ level. As a result, we can state that 1.15 % of the total knowledge score variance lies at school level, 9.42% at class level, 14.26 % at student level, and finally, 75.17% at the measurement occasion.

Subsequently, based on the theoretical framework, visual representation, group setting, and gender were entered into the model as potential explanatory variables. All predictors were included in the models as fixed effects. Adding these variables to the null model resulted in a

better model fit (X^2 = 55.59, *df* = 21, *p* < .001). Model 1 (Table 4) shows the results of this factorial model with main and interaction effects added to the model. The reference category is a male working individually and following a TSPW learning path. In the random part of Model 1, all variance in scores are significantly different from zero and significant at the *p* <.001 level, except for school level.

Student scores

Table 2.

Knowledge scores on pre- and post-test and significant differences between groups (left) and differences between knowledge tests (right).

	Knowledge scores		Significant differences
	Pre	Post	PrePost
Male, Indiv., TSPW	59.90	57.25 [d]	>.05
Male, Indiv., MGL	61.29	76.52 [ad]	**<.05**
Male, Collabor., TSPW	58.30	63.23 [a]	**<.05**
Male, Collabor., MGL	57.30	66.00 [c]	>.05
Female, Indiv., TSPW	55.06	63.85 [b]	**<.05**
Female, Indiv., MGL	55.92	72.22 [bc]	**<.05**
Female, Collabor., TSPW	58.41	64.51	**<.05**
Female, Collabor., MGL	46.57	54.16	>.05

Note. Indiv = individual; Collabor = collaborative; TSPW = Text, Schemes, Pictures and Web-based exercises learning path; and MGL = Mayer GuideLines learning path. Same superscripts denote significant differences between conditions within a test (*p* <.05). No significant differences were found between the conditions on the pre-test.

Figure 4 shows the drilled-down details of student scores, while Table 2 displays the knowledge scores on the pre- and the post-test. First, we notice students' scores are close together (between 55.05 and 61.29) at the pre-test measurement, except for females working collaboratively on a MGL learning path (46.57). Second, we observe that the two steepest slopes (i.e., students who learned the most from the intervention) are the females and males within the individual MGL learning path condition. These students received the highest post-test scores: 76.52 for males and 72.22 for females. On the other hand, the lowest scores on the post-test can be found for males working individually on a TSPW learning path and for females working collaboratively on a MGL learning path. The remaining four scores are closely bundled together (between 63.22 and 66.00).
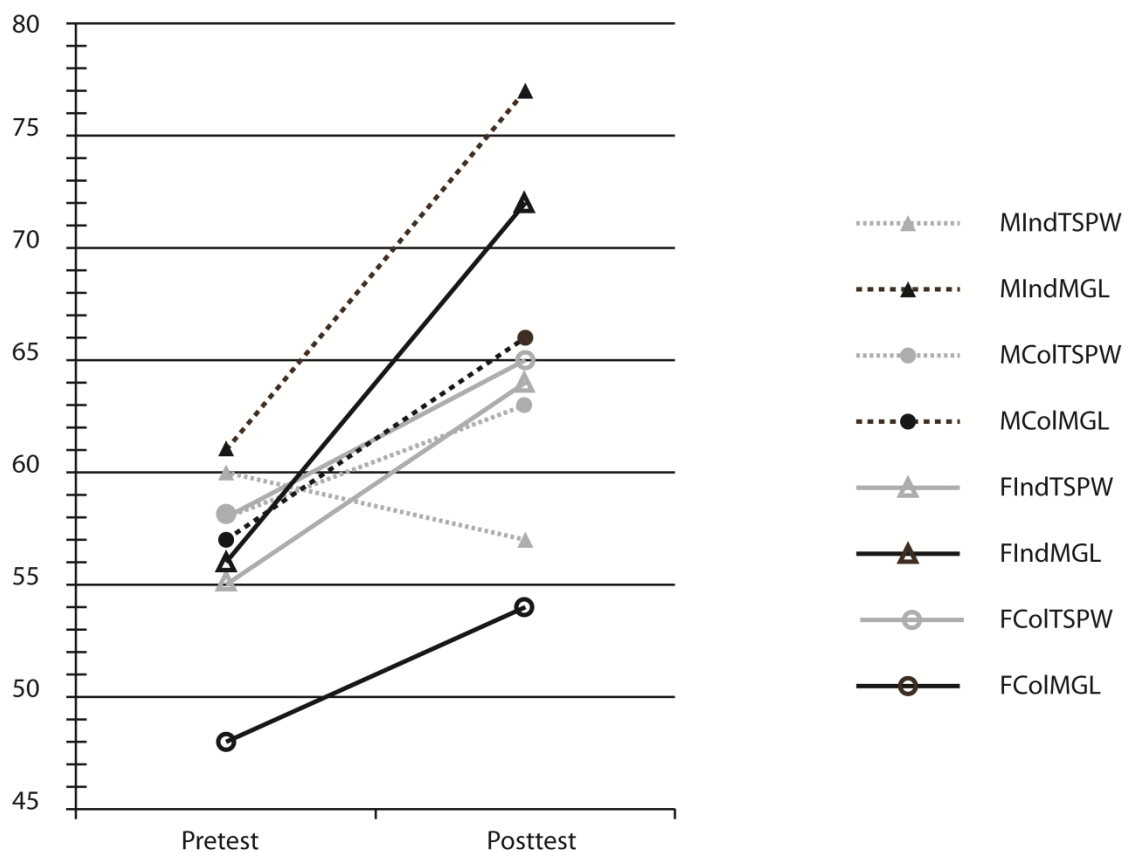
Figure 4. Knowledge scores in the pre-test and post-test for males and females.

Note: M = male; F = female; Ind = individual; Col = collaborative; TSPW = Text, Schemes, Pictures and Web-based exercises learning path; and MGL = Mayer GuideLines learning path.

Hypothesis testing

Given our first hypothesis (H1), we expected students following a MGL learning path to outperform students studying a TSPW learning path in their knowledge scores. As illustrated in Figure 4, the three highest knowledge scores on the post-test are attained by males and females following a MGL learning path within an individual setting (MIndMGL and FIndMGL), and by males in a collaborative setting (MColMGL). These findings suggest that optimizing a learning path with Mayer's Guidelines (2003) leads to better knowledge scores. However, when calculating the differences between the knowledge scores on the post-test (Table 2), this observation is only confirmed for students within the individual setting. MIndTSPW was significantly lower than MIndMGL and FIndTSPW was significantly lower than FIndMGL. However, MColTSPW was not significantly lower than MColMGL and FColTSPW was lower than FColMGL. Therefore, Hypothesis 1 can only be accepted for both males and females following the MGL learning path in an individual setting.

Table 3.

Hypothesis testing of learning performance on posttest.

Hypothesis testing	Results
Hypothesis 1	Supported for MIndMGL and FIndMGL
Hypothesis 2	No support
Hypothesis 3a	Supported for MIndMGL
Hypothesis 3b	No support2

Note. Indiv = individual; Collabor = collaborative; TSPW = Text, Schemes, Pictures and Web-based exercises learning path; and MGL = Mayer GuideLines learning path.

We also hypothesized students who collaborate in tackling the learning task would outperform students within an individual setting (H2). As depicted in Figure 4 and given the conclusion of Hypothesis 1, this was not the case. However, when observing the collaborative conditions (Figure 4), we notice a difference between males and females. On the one hand, males attain almost the same score under the collaborative condition, regardless of the version of learning path studied. This is confirmed when calculating the differences between the knowledge scores on the post-test (Table 2), as MColTSPW is not significantly lower than MColMGL. On the other hand, females have a higher score (Figure 4) on the post-test within the collaborative condition when they study with a TSPW learning path (as compared to a MGL learning path). However, when calculating the differences between the conditions on the post-test, FColTSPW is not significantly higher than FColMGL. In addition, the superiority of studying in the individual setting for males and females – already concluded in relation to Hypothesis 1 for the MGL learning paths – is also confirmed for females following a TSPW learning path (Table 2, FIndTSPW). In view of these findings, we therefore have to reject Hypothesis 2.

Following our third hypothesis, we expected to observe a significant interaction effect of gender when studying the two versions of the learning paths in combination with group setting. For males, we hypothesized (H3a) that, given the critical role of spatial ability, males would benefit most from the – with Mayer's guidelines (2003) – optimized learning path (MGL learning path).When testing Hypothesis 1, we found that males following a MGL learning path in an individual setting achieved better results than males following a TSPW learning path individually. We did not find similar results for males in the collaborative setting. Moreover, the superiority of the MIndMGL condition above MIndTSPW, MColTSPW and MColMGL is very obvious. When calculating (Table 2) the differences between knowledge scores on the post-test, MIndMGL was significantly higher than MIndTSPW and MColTSPW. When calculating the difference between the pre-test and the post-test for MIndMGL (Table 2), the increase in scores

was significant. As a result, hypothesis H3a can only be partly accepted for males following the MGL learning path in the individual setting.

For females, we hypothesized (H3b), in view of the group diversity literature and the positive impact web-based collaborative inquiry has on girls, that learning outcomes would be significantly higher when girls work collaboratively. As seen in Figure 4 and Table 2, females following a TSPW learning path achieve slightly better scores on the post-test within the collaborative condition as compared to the individual setting. However, when calculating the difference between these conditions on the post-test, FColTSPW was not found significantly higher than FIndTSPW. Females following a MGL learning path collaboratively achieved lower scores on the post-test as compared to girls under the individual MGL condition. When calculating the difference between these conditions on the post-test, FColMGL was not significantly lower than FlndMGL. Given the rather small difference between FColTSPW and FIndTSPW on the one hand and the problems arising from the unbalanced number of students in the FColMGL condition, we conclude there is no conclusive evidence to accept hypothesis H3b.

Discussion

In this research, we focused on the impact of the way a learning path is designed, an individual versus a collaborative setting, and gender differences between boys' and girls' learning outcomes in the context of a STEM secondary education setting.

Our findings showing the superiority of an (with Mayer's guidelines, 2003) optimized learning path are in line with previous research on the critical role of spatial ability within STEM-education (Super & Bachrach, 1957; Wai et al. 2009; Mayer & Sims, 1994). A MGL learning path leads to a better elaborated and structured course, and thus, offers a better spatial visualization than a TSPW learning path. These findings help explain the superiority of a MGL learning path within this research, and more specifically, when students (both males and females) are working alone.

These results are important for different stakeholders. We present both practical and theoretical implications. In the first place, our results are important for teachers when they are designing learning paths to be implemented in an online learning environment. In addition, the results are also important for instructional designers creating learning materials to be used, for example, in addition to school manuals.

The importance of visual representation has theoretical implications within STEM-education. More specifically, the critical role of spatial ability (Mayer & Sims, 1994; Wai et al.,2009; Ceci & Williams, 2010) was reaffirmed. Empirical evidence from longitudinal research shows that spatial ability is an important psychological characteristic among adolescents in general, but particularly beneficial for those who go on to develop high levels of STEM-expertise in their future careers (Wai, Lubinski & Benbow, 2009). Lubinski (2004) even advocates the potential usefulness of spatial ability to identify women with genuine talent for and interest in math/science careers. Moreover, he stresses that, on the basis of individual differences in spatial

ability, not only student selection, but also instruction and curriculum design should be taken into account.

Besides the strong impact of the way learning materials are visually represented, the impact of collaborative learning was less obvious. More specifically for females, the results demonstrate that collaboration does not automatically lead to better learning (Soller, 2001).

In their meta-analysis on the application of technology in support of collaborative learning, Resta and Laferrière (2007) refer to evidence that was found in favor of collaborative learning when groups are heterogeneous, including gender (see also Johnson & Johnson, 1996), but also to the tendency of women to be less active in learning groups (see also Felder, Felder, Mauney, Hamrin, & Dietz, 1995). Curşeu, Schruijer, and Boroş (2007) and Curşeu and Sari (2013) postulated that gender variety has a positive outcome on group cognitive complexity and that mixed-gender groups achieve better results. However, as gender diversity can also be differentiated as gender separation and gender disparity, negative influences on group effectiveness may have taken place. Thus, several negative influences on collaborative learning may have played a role within in our instant research, where membership in a group was formed randomly. Despite our extensive teacher scenarios and comprehensive briefing of the teachers, these factors can explain, in combination with the strong impact of the way learning paths are visually presented, why the collaborative conditions underperform within this research. Given the importance of the female presence within STEM, further research should try to overcome these negative influences on collaborative learning.

Finally, our research reveals the same contradictory findings concerning gender differences as stated in the meta-analysis of Voyer and Voyer (2014): females seem to score differently than expected (or even underperform) on achievement tests, while research shows persistently that females outperform males in actual school performance (i.e., school marks) regardless of the material studied. According to the authors, a possible explanation can be found in the way research is generally designed, and more specifically, the fact that the particular achievement tests used in the studies are not based on teacher marks. The authors also refer to Lindberg et al. (2010), who reported that male advantages on achievement tests increase with age, with a peak in high school, but decline for college and adult learners. This helps explain inconsistent findings in gender scores.

All findings discussed above lead to the conclusion that, although we tried to fill in the gap in research about the design and implementation of learning paths with respect to gender within the STEM field, several areas need to be improved and should be further researched.

Limitations

This quasi-experimental study took place in computer classes, involving 360 secondary school students. The fact that the study was performed in a regular school setting is advantageous for the ecological validity; however, there are some limitations.

Despite of all the advantages an authentic context has to offer, it also leads to uncontrolled and unexpected incidents. For instance, we asked teachers to refrain from any form of evaluation between the pre-test and the retention test, but due to a monthly evaluation system within the participating schools, teachers could not keep to this condition between the post-test and the retention test. As a result, we had to limit our focus to the pre- and post-test differences.

Another limitation was the unbalanced number of students across conditions, more specifically, within the collaborative condition of the MGL learning path (see Table 1). Due to a long-term illness, one teacher cancelled her participation; another teacher was fired. Given the last-minute character of these events, we were not able to recruit new teachers or to redistribute the teachers over conditions.

Third, within our research, complete randomization of students to conditions was not possible. As a result, complete classes were assigned to conditions. In this situation, multilevel analysis is the only appropriate statistical method, as ignoring group level (measurement occasions within students within classes within schools) would lead to overlooking the importance of group effects, and thus, violate the independence assumption (Nezlek, 2008). However, we would also like to note that the random assignment of individuals to particular conditions is sometimes impossible, impractical, or even unethical (Weathington, Cunningham & Pittenger, 2010).

Last, our results on collaborative learning indicate that follow-up research could benefit from more detailed information (Resta & Laferrière, 2007) on group composition of students (e.g., number of students within each group, same-sex vs. mixed-sex groups). Other aspects of collaboration that need to be more closely studied are the degree of experience of our stakeholders and the interaction between the teacher and the students.

Conclusion

Within this large-scale research, empirical evidence supported the importance of the actual design of a learning path and the impact of a collaborative versus individual learning setting on learning outcomes.

The importance of this study consists of, amongst others, (1) the implementation of learning paths, (2) in an LMS environment, (3) within the context of a STEM course, (4) involving 360 secondary school students and their teachers. This type of research is not only scarce (Kay & Knaack, 2008; De Smet & Schellens, 2009), but above all, important in a digitalizing world where the need for STEM education can be heard loud and clear within all levels of society.

Given the latest trends in online education and the focus on personalized learning and adaptive instruction; the initiatives undertaken in these fields by private grant-making foundations like the Bill and Melinda Gates Foundation to fill the education gap (e.g., their Adaptive Learning Market Acceleration Program, 2014), the rise of sophisticated adaptive learning software and platforms like Knewton (Time, 2013), and the partnerships between learning content publishers (e.g., Pearson, Sanoma Learning Solution) and software companies (e.g., Microsoft), we believe our research on learning paths can be an asset to help shape the future of learning and education.

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Appendix

Table 4.

Multilevel parameter estimates for the four-level analyses of learning outcomes.

Parameter	Model 0	Model 1
Fixed part		
Pretest	**57.18*** (1.50)**	**59.90*** (2.59)**
Collaborative setting (MColTSPW)		-1.60 (3.57)
Woman (FIndTSPW)		-4.85 (3.03)
Collaborative setting*Woman (FColTSPW)		4.95 (4.13)
MGL LP (MIndMGL)		1.39 (4.02)
MGL LP*Collaborative setting (MColMGL)		-2.43 (7.66)
MGL LP*Woman (FIndMGL)		-0,53 (4.57)
MGL LP*Collaborative setting*Woman (FColMGL)		-10.27 (8.54)
Posttest (MIndTSPW)	**7.31*** (1.09)**	-2.66 (2.59)
Post*Collaborative setting (MColTSPW)		**7.59* (3.62)**
Post*Woman (FIndTSPW)		**11.45** (3.74)**
Post*Collaborative setting*Woman (FColTSPW)		**-10.28* (5.09)**
Post*MGL LP (MIndMGL)		**17.88*** (4.18)**
Post*MGL LP*Collaborative setting (MColMGL)		-14.07 (8.78)
Post*MGL LP*Woman (FIndMGL)		-10.37 (5.73)
Post*MGL LP*Collaborative setting*Woman (FColMGL)		8.05 (11.01)
Retention test	**14.75*** (1.13)**	**12.93*** (2.59)**
Retention*Collaborative setting		2.04 (3.64)
Retention*Woman		-0.43 (3.74)
Retention*Collaborative setting*Woman		1.48 (5.11)
Retention* MGL LP		-1.03 (4.25)
Retention*MGL LP*Collaborative setting		0.00 (0.00)
Retention*MGL LP* Woman		6.58 (5.88)
Retention*MGL LP*Collaborative setting*Woman		0.00 (0.00)
Random Part		
Level 4: School		
Intercept/Intercept	3.19 (6.60)	0.00 (0.00)
Level 3: Class		
Intercept/Intercept	**26.15*** (10.86)**	**18.91*** (7.68)**
Level 2: Student		
Intercept/Intercept	**39.57*** (9.62)**	**42.24*** (9.40)**
Level 1: Knowledge test		
Intercept/Intercept	**208.57*** (11.42)**	**195.89*** (10.73)**
Model fit		
-2*loglikelihood:	8568.51	8512.92
x²		55.60
df		21
p		<.001
Reference model		Model 0

Note. Reference information on parameters and standard errors for Model 0 and Model 1 are in parentheses. M = male; F = female; Ind = individual; Col = collaborative; TSPW = Text, Schemes, Pictures and Web-based exercises learning path; and MGL = Mayer GuideLines learning path.
* *p* < .05 ** *p* < .01 *** *p* < .001

Bacteriën-les 4

tijd	Doelstelling	Leerinhoud	Activiteit leerkracht	Activiteit leerlingen
	omgesprongen worden met het gebruik van antibiotica.	ziektes veroorzaakt door virussen.	tegengaat heet penicilline. **Filmpje afspelen** Antibiotica werkt alleen tegen bacteriën. Bij een verkoudheid of griep, die veroorzaakt worden door virussen, helpt antibiotica niet. Net zoals zwembandjes enkel een kind kunnen beschermen tegen verdrinken. Bovendien worden sommige bacteriën door een verkeerd gebruik van antibiotica, resistent tegen die bepaalde soort antibiotica. Wat betekent het als een bacterie resistent is voor een bepaald antibioticum?	De leerlingen bekijken het filmpje Een leerling antwoordt.
5	Hygiëne De leerlingen kunnen de term hygiëne verklaren. De leerlingen kunnen voorbeelden geven van hygiënische handelingen.	Hygiëne Hygiëne= verzamelnaam voor handelingen die ervoor zorgen dat we gezond blijven.	Hygiëne **Projecteer de pagina 'hygiëne'.** We hebben daarnet allerlei manieren gezien die ervoor zorgen dat we snel kunnen genezen van een bacteriële infectie. Om gezond te blijven is het echter ook belangrijk om te voorkomen dat we besmet raken. Alle handelingen die we doen om gezond te blijven, noemen we hygiëne. Wat doen jullie bijvoorbeeld om gezond te blijven? Maak nu de oefening ' op de pagina toets je kennis.	Hygiëne De leerlingen geven enkele voorbeelden. De leerlingen maken de oefening van toets je kennis

Figure 5. Screenshot of a teacher scenario to guide the learning process. This document contains the following content: the recommended number of instructional minutes, the learning objectives, the learning content, the activities carried out by the teacher and the activities which must be done by the student.

4 | The differential impact of learning path based vs conventional instruction in science education

This chapter is based on:

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Chapter 4:
The differential impact of learning path based vs conventional instruction in science education

Abstract

Learning paths have the potential to change the teaching and learning interaction between teachers and students in a computer-supported learning environment. Empirical research about learning paths is scarce. Previous research showed that the low adoption of learning paths can be linked to the lack of knowledge about learning path design and their implementation. In the present study, which was set up in the context of a biology course in secondary education, 496 third grade secondary school students were assigned during classroom activities to either learning path based or conventional instruction. The aim was to analyse the differential impact of the instructional formats on learning outcomes, taking into account variations in group setting and group composition. Given the focus on science learning, also gender was taken into account.

Multilevel analysis was applied and the results provide empirical evidence for superior performance for both boys and girls in the learning path condition as compared to the conventional condition. In addition, when girls collaborate, they perform best within same-sex groups, whereas boys achieve better results in mixed-gender groups. Implications of the findings are important to tackle the gender gap in science learning. The findings result in guidelines for teachers who want to implement learning paths within an optimal learning environment design.

Introduction

In a study consulting 376 teachers from 70 secondary schools, De Smet and Schellens (2009) observed that 96% of the participating schools used a Learning Management System (LMS), but only 10% of the participating teachers actively used the learning path module. They concluded that despite the high adoption level of LMS within schools, the low adoption rate of learning paths suggests that teachers are unfamiliar with how learning paths can be designed and implemented.

As a result, De Smet, Schellens, De Wever, Brandt-Pomares, and Valcke (2014) studied the design and implementation of learning paths in an LMS. The impact of optimizing a learning path with guidelines derived from the Cognitive Theory of Multimedia Learning (CTML, Mayer, 2003) was studied within the context of a biology course. In addition, individual versus collaborative use and gender differences were considered when studying the impact on learning outcomes. It was found that students studying a learning path optimized with the CTML guidelines, especially when working alone, outperformed students in other conditions. The impact of collaborative learning was less obvious, more specifically for females. These results demonstrated that collaboration in a learning path does not automatically lead to better learning.

De Smet et al. (2014) describe a learning path as: "The LMS functionality to order a number of learning objects in such a way that they result in a road map for learners. Within a learning path, learning steps are structured in a general way (as a navigation map or a table of contents) or in a very specific sequenced way (e.g. 'complete first step 1 before moving on to step 2')" (p. 2). The most import building blocks of a learning path are the learning objects. Kay and Knaack (2007) define them as "interactive web-based tools that support the learning of specific concepts by enhancing, amplifying, and/or guiding the cognitive processes of learners" (p. 6). Learning paths can be created with authoring tools (e.g. eXe, Xerte) or can be programmed by software developers.

The purpose of the present paper is to support and extend previous learning path research. Building on the observation that optimizing learning paths on the base of the CTML guidelines was beneficial for student learning outcomes, we decided to adopt this design approach for the follow-up research. In addition, we build on research about collaborative learning. We expect students studying a learning path in a collaborative way to attain significantly higher learning outcomes compared to students learning individually. However, previous research is less conclusive as to the beneficial effect of collaborative learning. Possible causes are group composition (Resta & Laferrière, 2007), the role of gender within group composition (Johnson & Johnson, 1996) and the tendency of women to be less active in certain group settings (Felder, Felder, Mauney, Hamrin, & Dietz, 1995). This brings us to the central research problem: do learning paths have a beneficial impact on learning outcomes when studied in a collaborative way? We especially considered the role of gender and group composition. Since most of the teachers have not yet adopted learning paths (De Smet & Schellens, 2009), we implemented a design where conventional instruction is the control group and learning path based instruction is the experimental group.

In the next sections, we first present the theoretical base underpinning hypothesized differences between conventional instruction and learning paths, the rationale in relation to collaborative versus individual study of the learning paths and the impact of group composition. We also focus on gender, since it is of prime importance when studying collaborative learning (as discussed above) and also given the fact that our study is set up in the domain of science learning, where it is considered a key variable.

Theoretical and empirical framework

Learning paths and their potential topromote learning performance

The present study focuses on the impact of learning paths. The latter represent a specific functionality, made available via a Learning Management Systems (LMS; also referred to as Virtual Learning Environments, Digital Learning Environments, Course Management Systems or Electronic Learning Environments). LMS give educators tools to create an online course website and provide access to enrolled students (Cole & Foster, 2007). Most LMS provide a number of specific tools and functionalities to support learning. Dabbagh and Kitsantas (2005) distinguished 4 categories of web-based pedagogical tools: collaborative and communication tools (e-mail, discussion forums, and chat tools), content creation and delivery tools (upload course content and learning paths), administrative tools (course information, functions, interactions, and contributions), and assessment tools (tools to post grades etc.).

From a theoretical perspective, the potential benefits of learning paths are built on (1) the assumptions related to CTML and (2) the assumptions related to instructional technology conceptions.

Since most learning objects in a learning path have various functionalities and features (e.g., content, context, appearance, animation, behaviour, structure etc.), the rationale to use learning paths builds heavily on its multimedia nature. The Cognitive Theory of Multimedia Learning (CTML), as postulated by Mayer (2001, 2003) represents a framework to direct instructional design of multimedia materials and presents practical guidelines to design multimedia learning materials. For instance, the audio-visual elaboration of certain learning objects build on the dual channel assumption that states that learners have different channels (auditory versus visual) to process complex knowledge at the same time (Baddeley, 1992; Paivio, 1978, 1991). Exploiting these different channels allows studying more and more complex learning content. CTML also stresses the active learning assumption (Mayer, 2005). The (interactive) learning objects guarantee that learners are actively engaged in processing the multimedia environment. Cognitive processes involved are selecting (visual/audio), organizing (mental representation) and integration (visual, audio, and prior knowledge). The latter processes are consistent with evidence-based cognitivist learning principles that foster schema-development and subsequent learning performance (see Marzano, Pickering, & Pollock, 2001).

The sequencing of learning objects along a 'path' can – theoretically – also be linked to 'programmed instruction' principles as already defined by Skinner and principles already found in the 'teaching machines' of Pressey (1927, 1960) and Skinner (1954, 1958). Both programmed instruction and teaching machines reflect a systematic build-up of learning materials by following carefully defined steps. Moving from one step to the other depended on successful mastery of the former step. Skinner refers to 'operant condition' as the mechanism to ground learning. Emurian (2005) concluded that the step-by-step instructional design as found in Programmed Instruction is especially helpful when students access a new knowledge domain

because it provides study discipline, guarantees structured rehearsal and requires learners to attain a high achievement level. McDonald, Yanchar & Osguthorpe (2005) added that Programmed Instruction was found to be most effective when teachers did not use it rigidly, but combined it with other instructional methods and adapted the provided materials.

In their meta-analysis of 48 studies comparing final examination scores of secondary school students in mathematics and science, Kulik, Bangert, and Williams (1983) found 39 studies in favour of computer-based teaching and only 9 for conventional instruction. Similar findings within primary education were reported by Li and Ma (2010) for teaching mathematics, and for secondary education by Christmann, Badgett and Lucking (1997) and by Jenks and Springer (2002).

However, when comparing computer-based instruction with conventional instruction, several authors warn for pitfalls. While our learning paths are carefully designed with sequenced instruction, this is most probably not the case for conventional instruction (Jenks & Springer, 2002; Lockee, Moore, & Burton, 2004). Other factors that can be responsible for the apparent success of computer-based instruction are the novelty of the medium (Fletcher-Flinn & Gravatt, 1995), engaging only one teacher or two different teachers for both the experimental and control condition (Clark, 1983), or the study duration time (Cohen, Ebeling, & Kulik, 1981).

Collaborative learning and group composition

In this study we adopt the term 'collaborative learning' to refer to the engagement of all participants in solving a problem together (Roschelle & Teasley, 1995). Research among secondary school students on short-term collaboration, shows that collaborative learning mostly leads to better problem-solving and higher learning outcomes as compared to individual learning (Barron, 2003). When designing and researching the present online collaborative learning setting, we build on the considerable amount of research available in the field of Computer Supported Collaborative Learning (CSCL). The empirical evidence stresses that putting learners in a group does not guarantee spontaneous collaboration (Cohen, 1994), productive interactions (Barron, 2003), or effective learning behavior (Soller, 2001).

Dillenbourg, Baker, Blaye, and O'Malley (1995) stress variables that determine the conditions under which collaborative learning is most effective. Among others, they emphasize group composition as the most studied variable, besides task characteristics, the context of collaboration and the medium available for communication. Empirical studies focusing on group composition show that pairs are more effective than larger groups (Dillenbourg, 1996). This is consistent with Trowbridge (1987) who stated already three decades ago that students work by preference in pairs and in groups of three. Smaller groups enable students to fully participate and to establish group cohesion (Fischer, Kollar, Stegmann, & Wecker, 2013). Kobbe et all. (2007) stress the advantage of attaining more effective interaction in smaller groups.

Putting collaborative learning in a computer-based setting introduces additional levels of complexity. The asynchronous nature of online collaborative environments questions whether

students possess critical knowledge and skills to guide their task solution process (Fischer et al., 2013). Therefore, some authors propose using collaboration scripts to shape the way learners interact with one another (Kobbe et all., 2007). Kollar, Fischer, and Hesse (2006) and Kollar, Fischer, and Slotta (2007) make a difference between 'internal' (internalized by the learner) collaboration scripts and 'external' collaboration scripts (e.g. induced by a teacher or instructions on a website). Weaknesses in the mastery of internal collaboration scripts can be compensated by providing learners with explicit external collaboration scripts to guide them successfully in a collaborative situation.

Kollar, Fischer, and Hesse (2006) put forward 5 minimum characteristics of scripts in a CSCL setting: they focus on a clear objective, they engage in particular learning activities, they sequence required actions, they specify and distribute roles, and they contain a type of representation of the instructions to be presented to the learners. In the present study, we adopt explicit external collaboration scripts – called 'teacher scenarios' – to guide the collaborative learning process.

Gender

Present research takes place within the setting of STEM education (science, technology, engineering, and mathematics). Although STEM education is considered important in view of future career paths and socio-economic development, several countries report an alarming lack of interest in STEM related disciplines (European Commission, 2004, 2006; Organisation for Economic Co-operation and Development [OECD], 2007, 2008; U.S. Department of Education, 2007; National Governors Association, 2007). A recurrent problem within the STEM field is the underrepresentation of woman (European Commission, 2004, 2012). Traphagen (2011) indicated that woman (about 50% of overall U.S. population) only constituted 27 % of the science and engineering U.S. workforce in 2007.

This gender gap is in sharp contrast with the latest PISA tests (mathematics) where 15-year-old girls matched or even outnumber their male counterparts in the top performing countries (OECD, 2013); and with the observation that girls are more successful at school as they obtain higher grades and are less likely than boys to repeat a year (European Commission, 2006). Similar results were found in a recent meta-analysis by Voyer and Voyer (2014) taking 369 research samples into account, leading to the conclusion that females achieve higher marks for all course content areas. The European Commission (2012) presents the following causes of the gender gap: stereotypes found in children's books and school manuals; gendered attitudes of teachers, gendered advice and guidance on courses to be followed; and different parental expectations regarding the future of girls and boys.

Linking the gender discussion to the present study, we should bear in mind that some of our conditions under study, i.e. group setting and group composition, are believed to influence learning outcomes based on gender. Resta and Laferrière (2007), referring to Cranton (1998), Johnson and Johnson (1996), and Webb and Palincsar (1996), underscored the heterogeneous nature of groups due to a difference in participants' gender, status, culture, or expertise. In this

view, heterogeneous groups would result in more productive collaborative learning and are hypothesized to present learners with a broader range of perspectives. However, when focusing on gender, Felder et al. (1995) reported that females in mixed groups can experience disadvantages: they were frequently interrupted by males, felt uncomfortable when discussions arose, and in general felt that their contributions were undervalued. Curşeu, Schruijer, and Boroş (2007) and Curşeu and Sari (2013), building on the group diversity literature, put forward that gender variety has a positive outcome on group cognitive complexity and that mixed-gender groups achieve better results. However, group diversity can also be differentiated as gender separation and gender disparity, that are known to result in negative influences on group effectiveness.

Slotta and Linn (2009) found that web-based collaborative inquiry seems to be helpful in developing and maintaining positive attitudes towards science and science instruction. Raes, Schellens, and De Wever (2014) found that low achievers, and more specifically low achieving girls, benefited from this type of intervention. Especially the ability to discuss in small groups was believed to be beneficial. As mentioned earlier in this paper, Resta and Laferrière (2007) pointed at several studies supporting the claim that heterogeneous groups in terms of participants' gender are more productive (Cranton, 1998; Johnson & Johnson, 1996; Webb & Palincsar, 1996). In addition, Curşeu, Schruijer, and Boroş (2007); and Curşeu and Sari (2013) found that gender variety has a positive outcome on group cognitive complexity and that mixed-gender groups achieve better results; whereas Felder et al. (1995) reported in their research that females in mixed groups could be disadvantaged.

Research design

Research question and research hypotheses

This study researches learning outcomes of secondary school students who followed a biology course either via conventional instruction or via a learning path, and are working individually or collaboratively. Special attention is paid to group composition and gender. The following general research question guided our study: What is the differential impact of studying through a biology learning path versus through a conventional instructional format, considering a collaborative or individual learning approach and variations in group composition? Building on the available theoretical and empirical base, the following hypotheses can be linked to this research question, both on post- and retention test:

(H1): In the individual setting, both males and females studying via a learning path (LP) will obtain significantly better learning outcomes than students following the biology course via conventional instruction (Conv).

H1a: BoyLP scores higher than BoyConv

H1b: GirlLP scores higher than GirlConv

(H2): Both males and females studying a learning path in a collaborative setting, will attain significantly higher learning outcomes as compared to students studying the learning path on an individual base.

H2a: Bin2BoysLP (a boy in a same-sex collaborative group) scores higher than BoyLP

H2b: Gin2GirlsLP (a girl in a same-sex collaborative group) scores higher than GirlLP

H2c: BinMix (a boy in a mixed collaborative group) scores higher than BoyLP

H2d: GinMix (a girl in a mixed collaborative group) scores higher than GirlLP

(H3): Mixed-gender groups perform higher than same-sex groups.

H3a: BinMix scores higher than Bin2BoysLP

H3b: GinMix scores higher than Gin2GirlsLP

Considering the empirical data in relation to gender and STEM, we put forward a fourth hypothesis:

(H4): Girls perform higher than boys, independent from the instructional method used.

H4a: GirlConv scores higher than BoyConv

H4b: GirlLP scores higher than BoyLP

H4c: Gin2GirlsLP scores higher than Bin2BoysLP

H4d: GinMix scores higher than BinMix

Participants

Flanders' secondary education comprises of six consecutive years of study, starting at the age of 12. Fifteen teachers (N = 15, 5 males, 10 females), working in 13 different secondary education schools agreed to participate. Six of them had prior experience with previous learning path research (De Smet et al., 2014). Seven extra secondary education schools were selected in collaboration with a GO! staff member. GO! is one of the three main educational networks in Flanders and comprise 15% of secondary school education in Flanders. The GO! network is financed by the government, but functions independently of the Flemish Ministry of Education. In this way, every educational network has the autonomy to develop their own curriculum (including the subject content, competencies, skills, learning goals etc.) However, within an educational network, the curriculum within the selected classes and schools is identical.

Thirty-two classes were involved in the study. All students enrolled in these 9th grade classes (N= 496, 219 males and 277 females) participated in the consecutive activities during the study. On average, students within the 9th grade are 15 years old. Figure 1 shows the participants flow chart.

Belgium, and Flanders in particular, is one of the world's most urbanized countries in the world (United Nations World Populations Prospects, 2011). As a consequence, all participating schools are situated in an urban area. Prior to the study, informed consent to use the data for research purposes was obtained through the different school teachers.
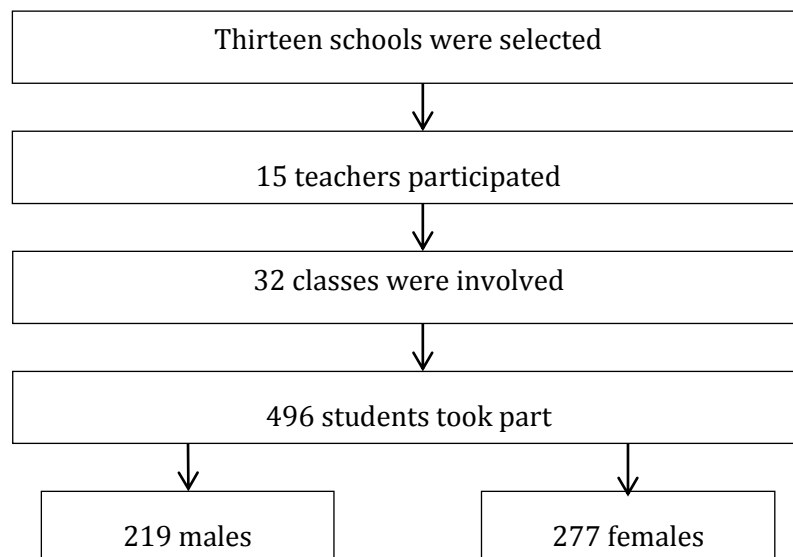
Figure 1. Participants flow chart.

The biology 'Bacteria' learning path

A prior study on the design of learning paths by De Smet et al. (2014) showed that a learning path consisting of multimedia learning objects, that build on text, schemes, pictures and web-based exercises and optimized by applying Mayer's (2003) multimedia guidelines, guaranteed superior learning outcomes. Given the positive evaluation of this experimental learning path about 'bacteria collection and growth' by teachers and students, the same set of materials was used for the present study.

Figure 2. Images on the bacteria topic from the learning path: picture gallery (above), multiple choice questions (left) and a schema (right).

During our prior research, teachers suggested several small improvements, mostly spelling corrections and suggestions on content or exercise level. A recently graduated biology teacher, who was also involved in the first research, was hired to adapted the old learning path based on the teacher's feedback. In the last phase, our freshly adapted learning path was reviewed for a final version by 10 pre-service teachers majoring in biology.

Individual versus collaborative study of the learning paths

Within this study, students work either alone or in pairs. As remarked by Fischer, Kollar, Stegmann, and Wecker (2013), research on collaborative learning stresses the need to adopt internal or external collaboration scripts (see also Kollar, Fischer, & Slotta, 2007). As defined by Kollar, Fischer, and Hesse (2006), scripts contain a learning objective, a representation of the learning instructions, a series of learning activities and a clear sequencing of the required actions.

In this research, external collaboration scripts in the form of teacher scenarios were presented to the learners. Several additional reasons ground the adoption of teacher scenarios. First, Flemish teachers (pre-service teachers and in-service teachers) are used to work with lesson preparation templates; the teacher scenarios were based on these templates. Second, we build on empirical evidence about these teacher scenarios from our previous research (De Smet et al, 2014). Third, the scenarios guarantee the comparable and controlled nature of the teaching interventions in the different research conditions and settings. Different teacher scenarios were available depending the research condition (learning path/traditional and collaborative/individual), however they did not result in differences in the content to be studied about bacteria.

Research instruments: learning performance

In order to test the knowledge of the students, a pre-test, a post-test, and a retention test were administered from the students. A recently graduated biology teacher created a learning objective matrix. For each row, the table contained a particular knowledge element about 'bacteria collection and growth' taken from the official biology curriculum. In the subsequent columns, one or more questions were formulated that tested a different level along the knowledge dimension of Bloom's revised taxonomy (Krathwohl, 2002): factual knowledge, conceptual knowledge and procedural knowledge. The metacognitive knowledge level was not considered in this study.

This procedure resulted in developing at least 5 questions for 15 learning objectives; an item test bank of 97 test items was developed. This large amount of questions enabled the researcher to develop different parallel test versions to be used at different stages in the study. To check the quality of the questions, ten pre-service teachers, under the supervision of their lecturer, reviewed, discussed and adapted questions when necessary.

All questions were – building on the learning objective matrix – used to develop three parallel test versions. Finally, three classes, containing 63 students participated in a try-out phase. This enabled item analysis to improve the quality and accuracy of the true/false items. A combination of item difficulty (p-value) and item discrimination (PBS or Point-Biserial correlation) was taken into account. Items with p-values above .90 and PBS-values near or less than zero were removed from the tests (Division of Instructional Innovation and Assessment, University of Texas at Austin, 2007). As a result questions were removed from the original 97 questions; others were

adapted in views of obtaining the final test item bank that consisted of 85 questions. This item test bank was used to develop 6 parallel sets of items (A, B, C, X, Y and Z), consisting of 14 questions each. Next, test versions were paired in such a way that each individual series reflected an item overlap with a parallel version: test 1 (XY), test 2 (YZ), test 3 (ZA), test 4 (AB), test 5 (BC) and test 6 (CX). Tests were randomly assigned to all 32 classes, e.g. class 7 received test 1 as pre-test, test 3 as post-test and test 5 as retention test, where class 8 received test 3 as pre-test, test 5 as post-test and test 1 as retention test etc.

This approach was applied to make sure that difficulty levels of pre-, post-, and retention test were exactly the same and to correct for potential bias (remembering answers, enlarged focus on certain elements, etc.).
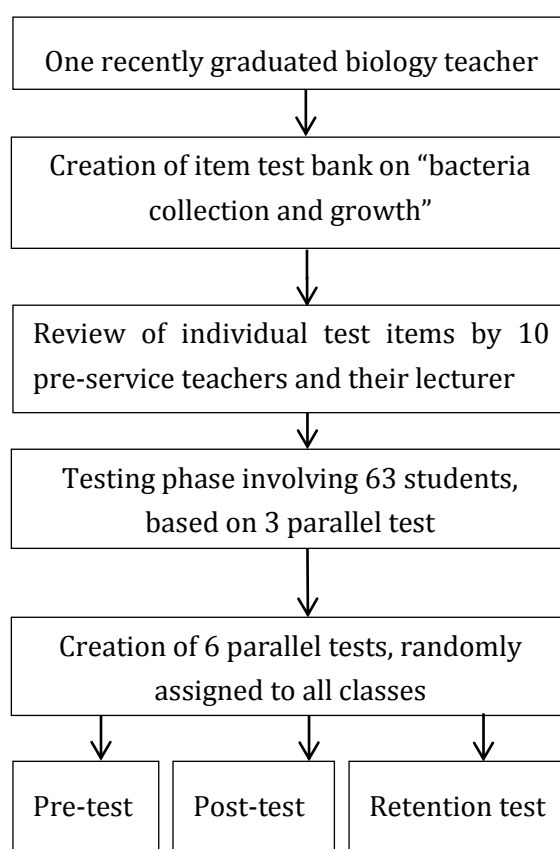
Figure 3. Creation process of the learning paths and the knowledge tests

Research procedure

Based on the independent variables: instructional method, collaborative/individual setting, group composition (only males, only females and male/female); eight research conditions were established in this study. In addition, also the gender of each respondent was considered in relation to each research condition (see Table 1).

Table 1.

Overview of research conditions and number of participants across conditions.

	Individual				Collaborative			
	Conventional		Learning path		Learning path			
	BoyConv	GirlConv	BoyLP	GirLP	Bin2BoysLP	Gin2GirlsLP	BinMix	GinMix
Males	27	0	97	0	66	0	28	_
Females	0	55	0	107	0	88	_	28
Total	27	55	97	107	66	88	28	28

Note. Conv = Conventional Instruction, LP= Learning Path, Bin2BoysLP = a boy in a same-sex collaborative group, Gin2GirlsLP = a girl in a same-sex collaborative group, BinMix = a boy in a mixed collaborative group and GinMix = a girl in a mixed collaborative group

Complete classes (N = 32) were assigned to either the conventional instruction condition or the learning path condition. Within the learning path condition, students were at random assigned to either work collaboratively or individually. All teachers in the learning path condition received a box containing a research guideline, a comprehensive teacher scenario, the time schedule, two versions of the learning path (HTML and SCORM) and all the tests (on paper). During an oral explanation, the researcher and the teacher discussed the proposed timing, the workflow and technical information concerning learning paths (and integration within their Learning Management System). The researchers' e-mail address and emergency phone number was provided, in case they needed information or assistance. Only a few minor technical and procedural questions emerged.

Within the learning path condition, we demanded all teachers to assign their students randomly to individual work or to collaborative work in pairs. As to pairs, students were randomly assigned to either a mixed-gender or a same-gender group. Pairs were established for the entire duration of the study (4 lessons). A form was provided to the teachers to document student details: name, gender, group setting (individual or collaborative), name and gender of the other group member when working in pairs, and presence or absence during each consecutive session. It was mandatory that all lessons in the experimental condition took place in the computer class.

Classes assigned to the conventional research condition did not receive additional materials. Teachers worked with their traditional textbook and their traditional learning activities, but worked in view of the same learning objectives and timeframe as the teachers/classes in the experimental condition. As discussed above, this is guaranteed by the detailed curriculum all teachers within an educational network are following. None of these classes were involved in collaborative work.

Statistical analysis

Dillenbourg, Baker, Blaye, and O'Malley (1995) state that research on collaborative learning can be based on either the individual or the group as the unit of analysis. Since the present research focuses on the learning outcomes of individual learners, we do not centre on group scores as the unit of analysis, but on data from individual group members. Kirschner, Paas, and Kirschner (2009) argued that the latter leads to 'more informative and straightforward results' than conclusions based on group performance.

Our data reflect a hierarchical structure (i.e. students in classes from different schools were offered knowledge tests at three separate moments). It might, therefore, be concluded that individual observations are not completely independent, since students share a common history and experiences (Hox, 1994). Ignoring this structure, could result in violating assumptions of regression analysis, since knowledge scores of individual students enrolled in the same classes might be interdependent, and thus lead to the fact that school-level and class-level are overlooked. In this respect, Diez-Roux (2000) and Nezlek (2008) suggest to apply Multilevel Modelling as an alternative statistical approach. Goldstein (2003) stated that the multilevel approach is especially important in the case of repeated measures data because there are very few level 1 units (tests) per level 2 unit (students). He also added to this that in general multilevel is even more conservative than a traditional regression analysis where the presence of clustering is ignored (Goldstein, 2003).

To develop the multilevel model, we build on Van Der Leeden (1998) who considers repeated measures as a hierarchical structure since these measurements are nested within individuals. Following this rationale, our knowledge tests are defined as the first level, students as the second level, classes as the third level and schools as the fourth level. MLwiN software (Centre for Multilevel Modelling, University of Bristol) was used to analyse the hierarchical data structure (Nezlek, 2008; Rasbash, Steele, Browne, & Goldstein, 2009).

A two-step procedure was followed to analyse the effects of 4 independent variables (instructional method, collaborative/individual setting, group composition and gender) on the dependent variable, i.e. learning outcomes. The subsequent models being tested following this procedure are summarized in Table 4 (in annex). To start, we tested the four-level conceptual null model (Table 4, Model 0) that serves as the baseline model. This unconditional null model (without any predictor variables) incorporates the overall pre-test, post-test and retention score from all students, classes and schools. The second step implied the addition of the seven

research conditions in the fixed part of the model, while allowing cross-level interactions between students, class, and school characteristics. This resulted in Model 1 (Table 4).

We first report the model that was built, the descriptives and a detailed overview of the multi-level analysis results. Next we test the four hypotheses on the base of the findings.

Results

Model building

We present the analysis results following the two-step procedure described above. The first model is the conceptual unconditional null model (Table 4, Model 0) predicting the overall pre-test (M = the intercept, or 38.67 out of 100), post-test (M = 45.07 = 38.67 + 6.40) and retention test score (M = 46.39 = 38.67 + 7.72) across all students, classes, and schools. This null model shows that, without taking into account a particular research condition, but controlling for the nested data structure, students are scoring significantly higher on the post- as well as the retention test as compared to the pre-test. This null model also results in four variance estimates as shown in the random part of the model, one at school level, one at class level, one at student level and one in relation to the measurement occasion. The variance for school level was found to be insignificant, class level is significant (p = .008) at the p <.01 level and student and test level are significant at p <.001. From the results, we can conclude that 4.33% of the total knowledge score variance lies at school level, 14% at class level, 17.32% at student level and finally 64.35% at the measurement occasion. According to Aarts, Verhage, Veenvliet, Dolan, and van der Sluis (2014), the explained variance in multilevel analysis of the levels can be interpreted as effect size.

In our second model, based on the theoretical framework, we investigate the additional impact of instructional format, collaborative/individual setting and gender as potential explanatory variables. As can be seen in Model 1 (Table 4), adding these variables to the null model resulted in a better model fit (X^2 = 1271.6, df = 23, p < .001). The reference category (BoyConv) is the score of a male student, who is working individually and following the 'bacteria topic' via conventional instruction.

When looking at the results of Model 1 (Table 4 in appendix) we found no significant differences between the conditions at the pre-test. This finding is logical and in line with what we expected, as the pre-test was administered before any of the interventions took place. Nevertheless, we found significant differences between groups and between knowledge tests. We shall, therefore, highlight the key findings of the research and focus on the significant results.

Student learning performance

Table 2.

Knowledge scores on pre-, post- and retention test and significant differences between groups (left) and differences between knowledge tests (right).

	Knowledge scores and significant differences between groups			Significant differences between tests		
	Pre	Post	Retention	PrePost	PostRet	PreRet
BoyConv	37.22	41.36[a]	37.00[fghi]	>.05	>.05	>.05
GirlConv	37.72	45.38	41.84[j]	**<.05**	>.05	**<.05**
BoyLP	38.81	44.16[b]	45.09[fk]	**<.05**	>.05	**<.05**
GirlLP	38.04	44.15[c]	49.88[gjklm]	**<.05**	**<.05**	**<.05**
Bin2BoysLP	39.83	41.81[d]	43.18[ln]	>.05	>.05	>.05
Gin2GirlsLP	37.22	44.66[e]	48.33[hno]	**<.05**	**<.05**	**<.05**
BinMix	43.15	51.41[abcde]	49.14[ip]	**<.05**	>.05	>.05
GinMix	40.38	46.88	41.48[mop]	**<.05**	>.05	>.05

Note: Conv = Conventional Instruction, LP= Learning Path, Bin2BoysLP = a boy in a same-sex collaborative group, Gin2GirlsLP = a girl in a same-sex collaborative group, BinMix = a boy in a mixed collaborative group and GinMix = a girl in a mixed collaborative group. Same superscripts denote significant differences between conditions within a test (p <.05). No significant differences were found between the conditions on the pre-test.

To report the findings on our hypotheses, we build on Figure 4, depicting the particular student performance scores which are based on the multilevel analyses reported in Table 4. Table 2 displays the knowledge scores on the pre-, post- and the retention test, the differences between the groups and the differences between the knowledge scores.

First, it can be noticed that the pre-test scores are close to one another (all between 37.22 and 43.15). Differences become more distinct when looking at the post-test scores (between 41.36 and 51.41) and the retention test scores (between 37.00 and 49.88). Second, Table 2 indicates (with common superscripts) which groups are significantly different from each other on the post- and retention test. Third, when calculating the differences between tests, Figure 4 illustrates that the learning slopes (i.e. the increase or decrease between test scores at two different measurement occasions) show variation. When observing the slopes between the pre-test and the post-test, we observe they are all increasing; only the slope for Bin2BoysLP stands out as it seems to increase less. Between the post-test and retention test, four slopes are increasing and four are decreasing. Significant differences between these tests are listed in Table 2.
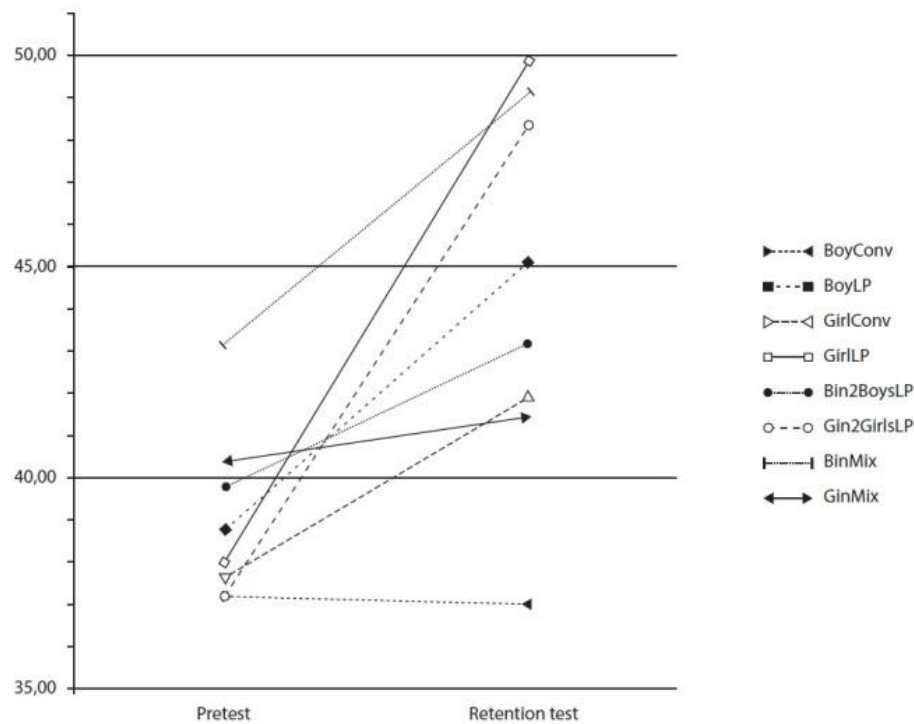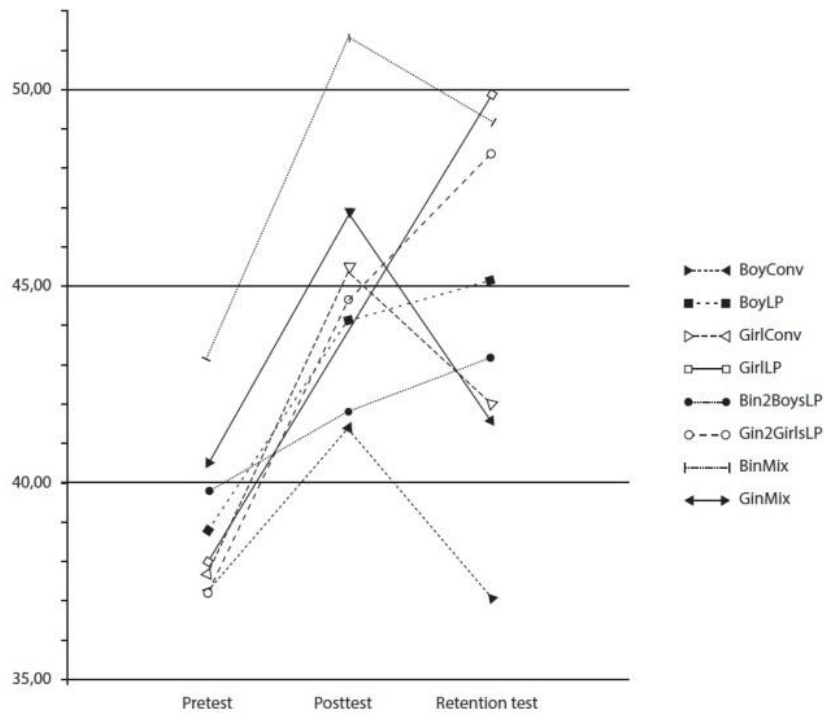
Figure 4. Pre-test, post-test and retention test (above) and pre-test and retention test for boys and girls in the different research conditions (below).

Note. Conv = Conventional Instruction, LP= Learning Path, Bin2BoysLP = a boy in a same-sex collaborative group, Gin2GirlsLP = a girl in a same-sex collaborative group, BinMix = a boy in a mixed collaborative group and GinMix = a girl in a mixed collaborative group.

Hypothesis testing

Table 3.

Hypothesis testing of learning performance on post- and retention test.

Hypothesis testing	Results
H1a	Supported on retention test
H1b	Supported on retention test
H2a	No support
H2b	No support
H2c	Supported on post-test
H2d	The inverse was true on retention-test
H3a	Supported on post-test
H3b	The inverse was true on retention test
H4a	No support
H4b	Supported on retention test
H4c	Supported on retention test
H4d	The inverse was true on retention-test

Given our first hypothesis (H1), we expected that students studying via a learning path (BoyLP, GirlLP) would attain higher learning outcomes than students in the conventional condition (BoyConv, GirlConv). Figure 4 seems to largely confirm this hypothesis. When calculating the differences between the scores on the post- and the retention test, Table 2 shows that only the differences on the retention test were found significant. Based on these scores, we can conclude that both hypotheses H1a for boys and H1b for girls were confirmed on the retention test: studying via a learning path leads to better learning outcomes than conventional instruction.

We hypothesised (H2) that students who study learning paths in a collaborative way would outperform students within an individual setting. As can be observed in Table 2, no significant differences on both post- and retention test were found between Bin2BoysLP and BoyLP (H2a) and between Gin2GirlsLP and GirlLP (H2b), and thus as a result, these hypotheses can be rejected . When controlling for hypothesis H2c, we notice that a boy in a mixed-gender condition (BinMix) scores better than a boy in the individual condition (BoyLP) on both post- and retention test, however the difference between BinMix and BoyLP was only significant on the post-test. When testing for hypothesis H2d, we observe a significant difference on the retention test, but the inverse of what was supposed in H2d: girls working individually on a learning path

perform better than girls in mixed-gender groups. This leads to the observation that the presence of a girl is beneficial for boys in a mixed-gender group, whereas girls perform better when working alone.

Our third hypothesis (H3) predicts that group composition plays an important role, more specifically mixed-gender groups (BinMix and GinMix) are expected to perform better than learners in same-sex groups (H3a for Bin2BoysLP and H3b for Gin2GirlsLP). Table 2 indicates that boys in the mixed-gender group score better than the boys in the same-sex group on both post- and retention test, but only the difference on the post-test was found significant. As a result, H3a is accepted on the post-test. The results show a somewhat different picture for the girls. When calculating the difference for the girls between GinMix and Gin2GirlsLP, we found the a significant difference on the retention test. But again, this leads to the inverse of an original hypothesis (H3b) and to the un-expected conclusion that girls who work collaboratively in same-sex groups in the learning path condition perform better than girls in the mixed-gender groups. In other words, the data seems to suggest that mixed-gender groups are more beneficial for males, while females score better in same-sex groups.

Following our fourth hypothesis (H4), we expect that girls perform better than boys, independent from the instructional method used. When comparing the results to check for H4a between GirlConv and BoyConv, we found no significant differences on the post- and the retention test and thus we reject hypothesis H4a. Girls in the individual learning path condition (GirlLP) perform better on the retention test as compared to boys working individually with a learning path (BoyLP). The difference was significant, leading to the acceptance of hypothesis H4b on the retention test. A similar result on the retention test led to the acceptance of H4c, where we notice that girls working collaboratively in same-sex groups (Gin2GirlsLP) achieve better results than boys in same-sex groups (Bin2BoysLP). This was not the case for H4d, as girls in mixed-gender groups (GinMix) score less than boys in a mixed-gender group (BinMix) on both post- and retention test. A significant difference can be noticed on the retention test, or in other words, the inverse of hypothesis H4d is true. These data put forward that in the learning path condition, girls outperform boys when working individually or collaboratively in same-sex groups.

To conclude, we found evidence that both boys and girls in the individual setting score better in the learning path condition as compared to the conventional condition. Second, we found no support for the beneficial impact of collaborative learning, except for boys in a mixed-gender group. Third, mixed-gender groups are more beneficial for males (on the post-test), whereas females score better in same-sex groups (on the retention test). Fourth, girls perform better than boys when working individually in the learning path condition and when working collaboratively in same-sex groups.

Discussion

Within this research we focused on the effectiveness of learning paths, collaborative/individual instructional settings and the impact of group composition and gender in the context of a STEM secondary education setting.

Our results are important for different stakeholders and lead to both practical and theoretical implications.

First, our findings showing a superiority of studying individually with a learning path as compared to conventional instruction on retention test scores, are in line with previous research by Christmann et al. (1997) and Lockee et al. (2004). In their meta-analysis, Kulik, Bangert and Williams (1983) noticed raised scores on retention tests, even several months after the completion of the instruction. Nevertheless they concluded that these effects were not as clear as the immediate effects on the post-testing. Similar results were reported in a later study (Kulik & Kulik, 1991) where they examined 20 studies on follow-up examinations. On the other hand, within the literature there is evidence for what is known as 'the testing effect', referring to the tendency that someone's long-term retention of knowledge is strengthened by testing it. Dirkx, Kester, and Kirschner (2014) recently confirmed this effect as they found that secondary school students benefited from testing "not only the retention of facts from a mathematics text, but also the application of the principles and procedures contained in that text" (p. 361). To summarize, the advantage of studying via computer-based instruction, in this research learning paths, was reaffirmed. However, future research is needed and should further investigate the exact conditions under which students benefit from this type of learning.

Second, we expected that students who study learning paths in a collaborative way, would outperform students within an individual setting. Except for the boys in a mixed-gender group, the results did not support our expectation. A possible explanation according to Fisher et all. (2013) is the lack of prior experience and knowledge regarding collaborative learning. He refers to the absence of 'internal collaboration scripts' as defined by Kollar, Fischer, and Slotta (2007), that guides students in their collaboration process. As a solution, Fisher et all. (2013) advice to use external collaboration scripts as they can help develop more elaborate internal collaboration scripts. Within this research we used teacher scenarios as a form of external collaboration scripts, but this might not have been enough to compensate the lack of experience from both the teacher and the students with collaborative learning.

Third, when gender and group composition were taken into account, a particular picture emerged. In the learning path condition, girls outperformed boys in the individual setting and in same-sex groups, but not in mixed-gender groups. In addition, we found evidence that mixed-gender groups are more productive when working collaboratively (Cranton, 1998; Johnson & Johnson, 1996; Webb & Palincsar, 1996), but only for boys. This suggests that males benefit from the presence of a female when working collaboratively. In contrast, we found support for the observations of Felder et al. (1995) that girls in same-sex groups perform better than within mixed-gender groups. According to Voyer and Voyer (2014), the male/female ratio plays an

important role: when there are more females than males in a group or when the male/female ratio is equal, group composition does play a role for math and science courses. They also stressed that age plays an important role, as the female advantage is almost exclusively reported in junior, middle and high school. An explanation for this advantage was provided by Kenney-Benson, Pomerantz, Ryan and Patrick (2006), in their research on the different way girls and boys approach schoolwork. Their research suggests that sex differences in children's achievement goals and disruptive classroom behaviour, influences their learning strategies. Females tend to focus on mastery goals over performance goals in task completion, whereas males tend to show the reverse approach. As mastery emphasis generally produces better marks than performance emphasis, this could explain the higher marks for females.

To put it clearly, we can conclude that more classroom research is needed to establish the generality of the present findings.

Limitations

This study, involving 496 students, 32 classes and 15 teachers from 13 schools, took place in an authentic setting, which is advantageous for the ecological validity. However there are clear limitations.

First, although learners from 13 schools were involved, this sample was not the result of a selection on the base of a sample stratification framework. Second, we did not check for additional student background variables, such as previous educational history, prior knowledge, motivation, aspirations, social-economic status, etc. Third, despite the fact that a consistent set of knowledge elements were studied, the study was still short in duration. Fourth, the focus was on STEM related teaching and learning and within STEM only on biology related knowledge. Lastly, other efficacy and efficiency parameters should be considered when studying learning paths; e.g., duration, time investment, resource allocation, teacher conceptions, etc.

These limitations suggest that future research should replicate the learning path research while considering other student samples, a longer research period, the impact of mediating variables in learners, the impact of teacher related variables and a focus on other outcome measures. This will be helpful to develop a broader evidence base to direct the design and implementation of learning paths in education.

Conclusion

Our results are important for teachers who want to use learning paths within their classroom. We showed a significant impact of learning paths on learning, as they lead to higher scores compared to conventional instruction. Second we demonstrated that one should be careful when implementing collaborative learning in the context of STEM. Our research suggests that prior experience and knowledge regarding collaborative learning are essential. Third, we found that females perform better within same-sex group, while males achieve better results within mixed-groups. This knowledge can help a teacher to make the best choices when engaging in collaborative learning; especially considering the focus on mathematics or science learning.

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Appendix

Table 4.

Multilevel parameter estimates for the four-level analyses of learning outcomes.

Parameter	Model 0	Model 1
Fixed part		
Intercept (BoyConv at Pre-test)	**38.67*** (1.36)**	**37.22*** (3.61)**
GirlConv		0.50 (2.97)
BoyLP		1.59 (3.95)
GirlLP		0.82 (3.95)
Bin2BoysLP		2.62 (4.13)
Gin2GirlsLP		0.61 (3.99)
BinMix		5.94 (4.66)
GinMix		3.16 (4.58)
Post-test	**6.40*** (0.74)**	4.14 (2.95)
Post*GirlConv		3.53 (3.62)
Post*BoyLP		1.21 (3.41)
Post*GirlLP		1.98 (3.42)
Post*Bin2BoysLP		-2.52 (3.68)
Post*Gin2GirlsLP		2.70 (3.50)
Post*BinMix		4.12 (4.49)
Post*GinMix		2.36 (4.40)
Retention test	**7.72*** (0.74)**	-0,22 (2.99)
Retention*GirlConv		4.34 (3.64)
Retention*BoyLP		6.50 (3.45)
Retention*GirlLP		**12.07*** (3.48)**
Retention* Bin2BoysLP		3.56 (3.68)
Retention*Gin2GirlsLP		**10.73** (3.46)**
Retention*BinMix		6.21 (4.55)
Retention*GinMix		1.33 (4.470)
Random Part		
Level 4: School		
Intercept/Intercept	8.16 (8.96)	7.95 (9.46)
Level 3: Class		
Intercept/Intercept	**26.38** (9.61)**	**26.93** (10.19)**
Level 2: Student		
Intercept/Intercept	**32.65*** (5.43)**	**29.37*** (5.44)**
Level 1: Knowledge test		
Intercept/Intercept	**121.26***(5.76)**	**117.78*** (5.92)**
Model fit		
-2*loglikelihood:	11252.01	9980.40
x^2		1271.60
df		21
p		<.001
Reference model		Model 0

Note. Conv = Conventional Instruction, LP= Learning Path, Bin2BoysLP = a boy in a same-sex collaborative group, Gin2GirlsLP = a girl in a same-sex collaborative group, BinMix = a boy in a mixed collaborative group and GinMix = a girl in a mixed collaborative group

* $p < .05$ ** $p < .01$ *** $p < .001$

5 A qualitative study on learning and teaching with learning paths in a learning management system

This chapter is based on:

De Smet, C., Valcke, M., Schellens, T., De Wever, B., & Vanderlinde, R. (2015). *A qualitative study on learning and teaching with learning paths in a learning management system*. Manuscript submitted for publication.

Chapter 5:

A qualitative study on learning and teaching with learning paths in a learning management system

Abstract

This article presents the findings of a qualitative study about the adoption and implementation of learning paths within a Learning Management System (LMS). Sixteen secondary school teachers were involved in the study and questioned via semi-structured interviews. Two research questions are addressed: (1) what are the perceived conditions at school and at teacher level affecting the use of learning paths, (2) how are these conditions related to the expected outcomes? Research results show teachers are satisfied with learning paths as an educational tool, but reflect mixed feelings as to the impact on student learning outcomes. Clear barriers are identified at the school and teacher level, thwarting the implementation of learning paths in secondary education. The availability of a reliable and accessible ICT infrastructure, the quality of technical and pedagogical support, teacher professional development and the mastery of teacher Information and Communication Technology competencies, among others, were found to be essential.

Introduction

In their internationally recognized NMC Horizon Report; Johnson, Becker, Estrada and Freeman (2014) discuss several Information and Communication Technology (ICT) trends, expected to change education. They forecast Learning Management Systems (LMS) would underpin online, blended and collaborative learning in the short-term and foresee data-driven learning environments in the mid-term. According to the American technology website Techcrunch.com (Shieber, 2014), governments and venture capital firms have – up to date – never invested such amounts of money in the educational market.

Learning Management Systems (LMS) are information systems running on a server, offering various tools like document publishing, assessment modules, wiki, etc. LMS can be accessed using a web browser. Within the LMS, educational material is processed, stored and disseminated; teaching and learning related administration and communication is supported (McGill & Klobas, 2009). LMS originated in the late nineties and have seen a permanent market rise since then. The latest 2014 analysis by the Edutechnica blog (2014) of LMS usage involving all US higher education institutions, confirms that more than 90% of these institutions actively use an LMS. While the future for the LMS may sound promising, research remains scarce about the LMS learner's perception, experiences and satisfaction (Joo, Lim & Kim, 2011); their learning outcomes, as well as their teachers' motivation and training for using the system (Keramati, Afshari-Mofrad & Kamrani, 2011). In addition, recent research by Schoonenboom (2014)

investigated why some tools are used more than others, as little is known about the instructional use of the LMS.

Studying LMS and learning path usage:
Towards a theoretical model

In their LMS-related study, De Smet, Bourgonjon, De Wever, Schellens & Valcke (2012) investigated the instructional use and the technology acceptance of learning management systems by secondary school teachers. In this study, an extended TAM2-model (Venkatesh & Davis, 2000) was tested, by studying LMS usage intentions in terms of social influence, perceived usefulness and perceived ease of use. Next to the direct impact of teacher perceptions about the ease of use of an LMS and its usefulness, the researchers observed a direct and indirect impact of internal ICT support to understand LMS acceptance. The latter implies that supporting teachers at the school level plays an important role to use technology. In addition, it was found that a basic usage level (e.g. documents or exercises published by the teachers) is required before more advanced LMS functionalities (interactive activities) like collaborative writing, moderated discussions and learning paths) are being adopted.

The present paper focuses on 'learning paths', which is one of the more advanced LMS functionalities. Learning paths are described as "The LMS functionality to order a number of learning objects in such a way that they result in a road map for learners. Within a learning path, learning steps are structured in a general way (as a navigation map or a table of contents) or in a very specific sequenced way (e.g. 'complete first step 1 before moving on to step 2')" (De Smet, Schellens, De Wever, Brandt-Pomares & Valcke, 2014, p.2). The most import building blocks of a learning path are the learning objects. Kay and Knaack (2008a, p.6) define the latter as "interactive web-based tools that support the learning of specific concepts by enhancing, amplifying, and/or guiding the cognitive processes of learners".

The latter authors report in their literature review about a robust body of research discussing the design, development, reuse and accessibility of learning objects. However, little systematic research is available covering the actual use of learning paths in classrooms. The little available studies report on student perceptions or qualitative studies about learning outcomes. Research gaps are identified in relation to teacher attitudes about the use of learning objects in a real classroom and studies investigating the actual use of learning objects in a secondary school setting. In addition, Ozkan, Koseler and Baykal (2009) stress that research addressing the conceptualization and measurement of related learning outcomes - within educational organizations - is scarce.

To develop a theoretical base about conditions affecting the implementation of an LMS in general and learning paths in particular, we can build on the study of Piccoli, Ahmad and Ives (2001) who distinguish between a human dimension (including students and instructors) and a design dimension (including learning models, technology, learner control, content and interaction). The design dimension was examined in an earlier evaluative study, linking the

design, implementation and impact of learning paths with student learning outcomes (De Smet et al., 2014; De Smet, De Wever, Schellens & Valcke, 2015). Evidence was found about superior performance in the learning path condition compared to the conventional instruction (control condition). Furthermore, it became apparent that learning outcomes are influenced by design factors, next to implementation factors such as students working in groups or individually, and the group gender composition (same-sex or mixed-gender). In the present study, we firstly focus on the human dimension as defined by of Piccoli et al. (2001).

To develop a better insight into the human dimension, other researchers refer to 'barriers' hindering technology integration: external (first-order) and internal (second-order) barriers (Ertmer, 1999). According to Ertmer (1999), internal barriers are intrinsic to teachers and include their beliefs about teaching, their learning approaches and their teaching practice; external barriers are linked to computer access, training and support to help teachers becoming more effective or efficient. The external barriers hardly challenge underlying teacher beliefs. Consequently, Ertmer (1999) concludes that external barriers can be solved by providing the necessary resources, but internal barriers can only be changed by influencing a teachers' belief system and teaching practices. Research of Hermans, Tondeur, van Braak and Valcke (2008) confirms that teacher beliefs are at least as important as technology-related teacher characteristics to explain successful ICT integration. Teacher beliefs have therefore been explored by several researchers, since they play an important role in technology adoption (Smarkola, 2008) and technology integration (Ertmer, 2005; Ertmer, Ottenbreit-Leftwich, 2010; Hermans et al., 2008). In this respect, two approaches are frequently studied: teacher-centred versus student-centred beliefs about instruction (Kember, 1997), referring to the beliefs teachers hold about how technology enables them to translate those beliefs into classroom practice (Ertmer, 2005). Teachers holding a teacher-centred belief (based on a traditional learning model) rather adopt traditional teaching methods such as lecturing and focus on knowledge reproduction. Teachers reflecting student-centred beliefs engage in active learning environments that permit critical thinking, discovery, and collaboration (Chan & Elliot, 2004). But, some researchers (e.g. Liu, 2011) present less conclusive evidence about the relation between teacher beliefs and particular teaching practices and stress that the dynamics of this relationship needs further research.

Next to internal barriers (human dimension), the literature is – as already suggested above – clear about the impact of external barriers influencing technology integration; though little research is available in the domain of LMS and learning path usage. The distinction between internal and external barriers might neglect the interrelated nature of these variables; e.g., how professional development about LMS or a school level ICT-policy affects teacher beliefs. A more embracing perspective is needed. Therefore, we adopt the e-capacity framework of Vanderlinde and van Braak (2010) and conceptions derived from the research about user perceptions of e-learning systems (Liaw & Huang, 2007; Liaw, Huang & Chen, 2007; Liaw, 2008) to attain a more embracing perspective.

The e-capacity framework of Vanderlinde and van Braak (2010) deals with "creating and optimising sustainable school level and teacher level conditions to foster effective change through ICT" (p. 542). Figure 1 shows how consecutive circles encompass and interact with other processes and variables that affect the two central dependent variables: ICT curriculum implementation and ICT as a lever for instructional change.

School improvement conditions

ICT related school conditions

ICT related teacher conditions

Teachers' actual use of ICT

ICT curriculum implementation

ICT as a lever for instructional change
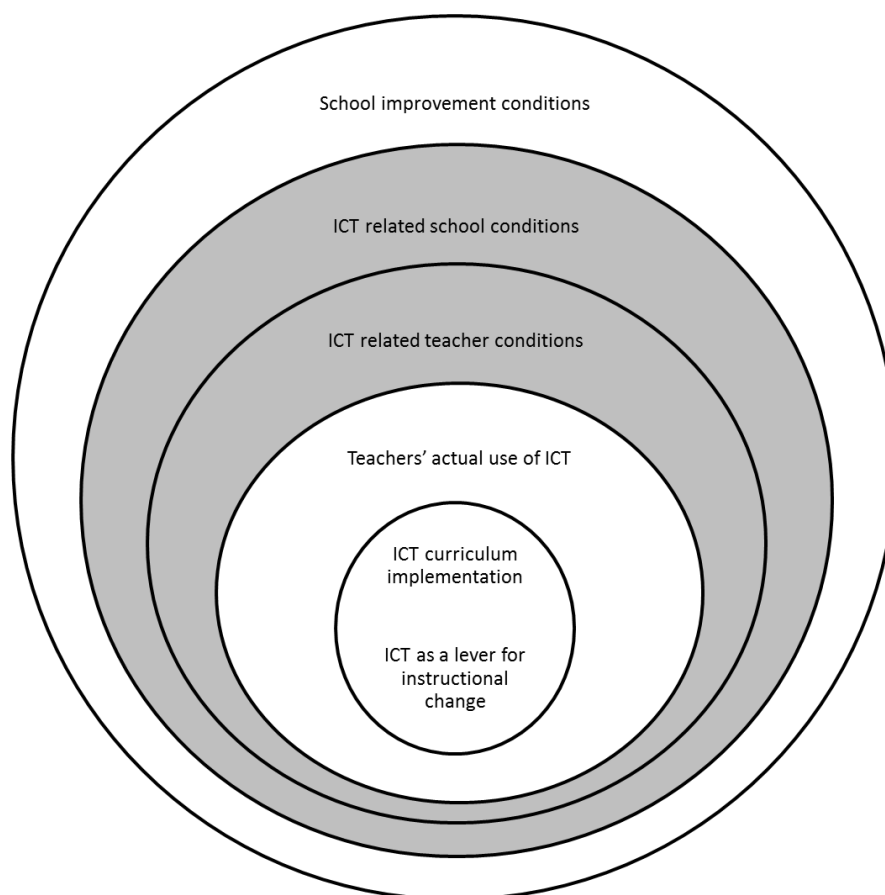
Figure 1. Model based on the e-capacity framework of Vanderlinde and van Braak (2010, p.254).

The framework consists of four mediating concentric circles with conditions that support ICT uses in education. In the present study we focus on the two inner 'circles' (see Figure 1, grey coloured): 'ICT related school conditions' and 'ICT related teacher conditions'. This particular emphasis does not neglect the potential impact of e.g., societal influences, leadership or decision making formats, but these are less the responsibility of the teachers and/or they are less related to their professionalism and expertise.

Also the work of Liaw and Huang (2007), Liaw, Huang and Chen (2007) and Liaw (2008) helps to develop this more embracing perspective on our research problem. These authors – on the base of the analysis of teacher interviews - suggest four interrelated 'environmental conditions' to develop effective and motivating e-learning environments as perceived by teachers: 1) useful environment characteristics, 2) effective learning activities, 3) enhanced environmental satisfaction, and 4) positive learner characteristics. Given our focus on the usage of LMS, we can redefine these conditions as follows:

'Useful environment characteristics' are related to the quality and multimedia features of the LMS. Next, 'Effective learning activities' provide learners and instructors with possibilities to share knowledge and experiences by using advanced LMS functionalities. Given our particular focus on learning paths within the LMS environment, we prefer to cluster these two conditions into 'Environmental characteristics'.

'Enhanced environmental satisfaction' refers to the feelings and the attitude towards the usefulness of the technology. In the context of the present study, we link this to teacher satisfaction with the student learning outcomes as a result of studying with learning paths. We therefore re-label this condition as 'Teacher satisfaction with the learning outcomes'.

'Positive learner characteristics' are defined as learner attitudes, motivation and beliefs that foster learning in the LMS. In the present study, - due to our focus on teachers - we ask teachers how they perceive student participation in the LMS'.

Table 1 integrates the theoretical frameworks discussed above in view of our study. Given the lack of in-depth research about the factors that affect learning in an LMS in general and with learning path in particular, we put forward the following two research questions:

1) What are the perceived conditions at school and at teacher level affecting the use of learning paths?

2) How are these conditions related to expected outcomes?

Table 1.

Main themes, sub themes and concepts used to explore and map our research questions.

Themes	Sub themes	Concepts
ICT related school conditions	ICT infrastructure	Hardware, software, connectivity, peripherals, and access to and availability of ICT related resources
	ICT support	Technical and pedagogical support, often by a ICT coordinator
	ICT policy plan	A schools' vision about the use of ICT as agreed upon by the school team
ICT related teacher conditions	Teacher professional development	Internal and external ICT training courses
	Teacher ICT competencies	Knowledge, skills and attitudes about the use and integration of ICT in the classroom
Environmental conditions	Environmental characteristics	The nature and quality of the LMS and/or learning paths
	Teacher satisfaction with the learning outcomes	Teacher satisfaction with student learning outcomes
	Positive learner characteristics	Perceived student participation in the LMS

Research design

A qualitative study was set up, building on data gathered during semi-structured interviews. These interviews were set up after teacher involvement in two quantitative studies about the impact of studying with learning paths in science education (De Smet et al., 2014; De Smet, De Wever, Schellens & Valcke, 2015). In a pre–post–retention repeated-measures design, involving learners in control and experimental conditions, learning path functionalities were studied in more detail. An experimental learning path about 'bacteria collection and growth' and complementary didactical materials were used with secondary school students. This research context guarantees that all teachers involved in the present study have comparable experience with LMS and learning paths.

Sample

In view of the former quantitative studies and the present qualitative study, 13 schools of the GO! Network were contacted. All biology teachers, contracted in these schools were willing to participate in the studies. The GO! Network is one of the three dominant educational authorities organising education in Flanders, the Dutch-speaking region of Belgium. This resulted in a total of 16 teachers (12 female and 4 male teachers). This gender distribution is typical for the secondary education context in Flanders where 60% of all secondary school teachers are female (Pynoo, Kerckaert, Goeman, Elen & van Braak, 2013). The biology education studies were set up with students from grade 8, who are on average 15 years old.

Interview instrument and procedure

Twenty pre-defined questions were presented following the semi-structured interview protocol (Taylor & Bogdan, 1998). The questions focused subsequently on teachers' conditions (ICT experiences, expertise etc.) and school conditions affecting their LMS and learning path use, as well as their perceptions and expectations about the LMS and learning path next to student characteristics and learning outcomes. Teachers were also invited to bring up additional questions and remarks.

The interviews were carried out on a one to one base and lasted between 30–45 minutes each. All sessions were recorded on videotape and transcribed by a third person. Informed consent was obtained from all participating teachers as to the anonymous recording, transcription and analysis of the interviews.

Coding and analysis procedure

During the coding-phase of the analysis, the first author was assisted by a junior researcher, who is an experienced secondary school teacher. She received training in view of the coding process.

All interview transcripts were split up into individual meaningful units. Graneheim and Lundman (2004) define meaningful units as 'words, sentences or paragraphs containing aspects related to each other through their content and context' (ibid, p. 106). They also recommend 'condensation' as a process of shortening while preserving the core content, and not substantially changing this content. Next, the analysis procedure moved to abstracting the condensed text at a higher order level by adding codes or categories to the individual meaningful units. In other words, each interview was divided in shorter paragraphs, which in their turn were grouped into categories according to shared characteristics. The software package Nvivo was used for segmentation (identifying meaningful units) and categorization of the data. Results from NVivo were compared and discussed until a saturated list of codes was generated. Initially, these codes were freely generated to describe the key content of the interviews. Next these codes were clustered considering the theoretical base as reflected in Table 1 and based upon Vanderlinde and van Braak (2010), Liaw and Huang (2007), Liaw, Huang and Chen (2007) and Liaw (2008). Disagreement as to further coding was resolved after discussion. Interrater-reliability was calculated, reflecting a high level of agreement (96 %).

NVivo matrices were used to tabulate the coded units in the interviews. Following Coniam (2011), a matrix approach allows a researcher to develop a complete picture of the data, rather than selecting random quotes to suit biased ideas or presumptions. This approach also enables the researchers to develop a quantitative perspective of the qualitative respondents' data.

Results and discussion

As summarized in Table 2, analysis of the sixteen interviews resulted in three main coding themes. Of the themes coded, 16% were related to 'ICT related school conditions', 24% to 'ICT related teacher conditions' and 60% to 'Environmental conditions'.

Table 2.

Coding scheme overview and detailed percentages of categories coded.

ICT related school conditions	ICT infrastructure	Hardware	31
		Software	11
		Components	6
		Smartschool	13
		Internet	5
		Infrastructure failure	25
		Access and availability	7
	Total	Count	98
		% of ICT related school conditions	80%
	ICT support	Didactical support	17
		Technical support	0
	Total	Count	17
		% of ICT related school conditions	14%
	ICT policy plan	ICT policy plan	0
		Colleagues' vision on ICT	6
		School authorities' vision on ICT	2
	Total	Count	8
		% of ICT related school conditions	6%
	Total ICT related school conditions	Count	123
		% of total coding	16%
ICT related teachers conditions	Teacher professional development	Internal and external training courses	4
	Total	Count	4
		% of ICT related teachers conditions	2%
	Teacher ICT competencies	Didactical ICT-knowledge	34
		Technical ICT-knowledge	24
		Using new instructional methods	86
		Class management skills to integrate ICT in the classroom	46
	Total	Count	190
		% ofICT related teachers conditions	98%
	Total ICT related teachers conditions	Count	194
		% of total coding	24%
Environmental conditions	Environmental characteristics	Learning path design remarks (content, digital excercises, lab excercies etc.)	45
		Learning path instructional remarks	39
		Instructional wording	9
		Estimated instructional time	54
		Worksheets (iteration 2)	19
		Teacher scenarios	12
		Questionaires used (pre/post/retention)	24
	Total	Count	202
		% of Environmental conditions	42%
	Teacher satisfaction with the learning outcomes	Count	104
		% of Environmental conditions	22%
	Positive Learner characteristics	Remarks on the learners' ICT knowledge	24
		Learners' remarks on using new instructional methods	52
		Attitudes en beliefs	29
		Motivation	66
	Total	Count	171
		% of Environmental conditions	36%
	Total Environmental conditions	Count	477
		% of total coding	60%
Grand Total Coding		Grand Total Coding	794

Conditions at school and teacher level

ICT related school conditions

Within this cluster, 80% of the responses were coded as related to the ICT infrastructure subtheme, 14% focused on ICT support and 6% on the ICT policy plan.

The importance of the availability and reliability of an ICT infrastructure can be deduced from Table 2. Because of its importance, related problems and complaints were formulated in nine out of sixteen interviews, sometimes leading to the conclusion that using LMS in the classroom might become impossible. During our two quantitative studies, we required biology teachers to work during four consecutive hours in a computer classroom, however not all teachers were able to make reservations for the acquired number of hours. Some even reported that access to the infrastructure was not admitted at all.

"The same problem always arises: computer classrooms are ample available, and if they are, it is very hard to find a classroom with a sufficient number of operational computers with internet access." [Teacher 6]

Moreover, being successful in making a reservation does not guarantee availability.

"I reserved fifteen laptops, but only got nine. The previous teacher didn't properly return them as he was supposed to, and this happens all the time. That's inconvenient." [Teacher 8]

One teacher does only get access to a beamer in the biology classroom.

"We don't even have a computer in our classroom. We can pick up a laptop at the office, but if we need specific software installed, we have to reinstall it over and over again, because the program uninstalls automatically every time we shut down a computer. And they don't get it, that this is not working out". [Teacher 12]

A report by the European Commission (2013) on the use of ICT in education shows a computer/pupil ratio of 1 to 5 in grade 8. Belgium scores above average with a ratio of 1 to 4; Flanders scores even better with 1 to 2 (Pynoo et al., 2013). However, the EC report also stresses that insufficient ICT equipment is still a major obstacle to educational ICT use and that policies at infrastructure level are a matter of urgency. The high proportion of related teacher responses about the ICT-infrastructure reflects this concern. At least for the teachers involved in the present study, access to well-functioning infrastructure remains problematic.

Another conditional factor, determining the degree of ICT integration, is the availability to the teacher of technical and pedagogical support. In Flanders, support is mostly supplied by an ICT coordinator or a colleague from the same school (Tondeur, Van Keer, van Braak, & Valcke, 2008). But additional research of Devolder, Vanderlinde, van Braak and Tondeur (2010) adds that ICT coordinators adopt more than half of their time a technical role and only a third of the support time in educational role. The latter was confirmed by six teachers who mentioned technical support was provided, but none of them referred to the availability of pedagogical support. Most

teachers felt well supported - at the technical level - to integrate ICT in their teaching, but some teachers nevertheless perceived the quality of the technical support as rather poor.

"I asked the ICT coordinator for a login and a password to access the LMS, but several months later, I am still waiting for it. ... Two people were supplying technical support, but only one of them was capable to help us, and he recently moved to another school. The other one has been forced to do the job, but he is still unable to answer our questions". [Teacher 12]

In the latest MICTIVO report, which builds on active monitoring of the status of ICT integration in Flemish education, 99% of the ICT coordinators said they offered technical support and 69% refer to pedagogical support (Pynoo et al., 2013). Nevertheless, school principals called insufficient pedagogical support their major concern when being asked for factors that affect ICT use in their schools (European Commission, 2013). A similar observation and a clear call for further investment in human, technical and financial resources was formulated by The Flemish Education Council (VLOR, 2013), as they state that needs with regard to pedagogical and content related support are high and under pressure. Our observations and the reports from the Flemish Education Council consistently indicate that pedagogical support is available, at least theoretically, but that in practice this support is hardly effective or does not achieve its goal.

Although successful ICT integration is often preceded by the presence of an ICT policy plan (Vanderlinde et al., 2010), no responses in relation to an ICT policy plan were spontaneously reported. In addition, Hayes (2007) stressed the importance of the school leader's vision and support towards an ICT policy plan. In our research, two teachers explicitly mentioned their school principal during the interviews: one principal actively encouraged the teachers' participation in the learning path research; another one was very much open to new technologies and installed a (temporary) iPad classroom that was eagerly used during the LMS/learning path study lessons.

ICT related teacher conditions

As can be observed in Table 2, 2% of the ICT related teacher conditions were coded as indicators referring to teacher professional development and 98% referred to teacher ICT competencies.

According to Bingimlas (2009), the most cited barrier to successful ICT integration, is a lack of teacher professional development. In this study, few statements (only 2%) were made about internal (school as training location) or external (outside the school) professional development opportunities. One teacher stated, although she participated in several ICT courses, she did not feel confident to use ICT and still heavily relied on the ICT coordinator's support. Another teacher mentioned pre-service training did not pay enough attention to ICT classroom use. These observations are in line with the report of the European Commission (2013), where Belgium was mentioned as one of the two countries where teachers reflect a relatively lower level of confidence in their ability to perform operational tasks using ICT. In the report, this

result was linked to the percentages of grade 8 students in grade 8 being taught with the support of ICT. Whereas the average EU-number is 25%, this was only 13% in Belgium. In other words, these findings and our observations suggest an underinvestment in professional development of teachers in Belgium.

According to Drent and Meelissen (2008), innovative ICT usage implies teachers use ICT as a tool to pursue educational objectives. In the present study, the LMS tool was challenging as teachers had to teach on the base of learning paths. This LMS functionality is hardly used - i.e. 10% of all teachers indicated they ever used learning paths in their teaching - in Flemish secondary education (De Smet & Schellens, 2009). The importance of the teacher related ICT competencies can be deduced from the high proportions of interview units coded accordingly (i.e. 98%). The following four subthemes were identified: didactical ICT-knowledge, technical ICT-knowledge, using new instructional methods and class management skills to integrate LMS.

The most frequently mentioned feeling, in twelve out of sixteen interviews, is the loss of control when teaching with learning paths. Several teachers explained they prefer an active but more directive teaching role rather than letting students work more autonomously. Some teachers even tried to gain back some control:

"I added some work sheets... reformulated questions ... and added writing lines. I had to create structure. I just could not resist." [Teacher 9]

Another teacher was very negative in relation to teaching with LMS.

"I instructed via learning paths, but immediately afterwards, I started over from scratch, using my own teaching approach. I wanted all my students being taught the way I usually teach. Even if that meant they had to study the same material twice". [Teacher 4]

These observations and analysis results can be linked to the teacher beliefs discussed earlier. Several researchers stress learner-centred approaches (Ertmer, 2005; Inan, Lowther, Ross & Strahl, 2010). In the present study, teachers taught with learning paths that build on related student autonomy, collaborative learning, etc. As such, some of our teachers – adhering to a teacher-centred belief - were confronted with an incongruent instructional approach. Research shows that changes in teaching practise requires an extensive amount of time (Brinkerhoff, 2006) and is best implemented in small steps (Kanaya, Light & McMillan Culp, 2005). In the current study, there might have been a conflict between teacher beliefs and the research teaching approaches. Second, research also points at a lack of teacher competencies to explain resistance to change (Bingimlas, 2009). In this view, it is not surprising teachers have the feeling to lose control when having to teach via learning paths.

Based on the present analysis results, we have to conclude – focusing on school- and teacher conditions - that the e-capacities of the schools under study are underdeveloped. Teachers referred to critical missing conditions: a reliable and accessible ICT infrastructure, the availability and quality of technical and pedagogical support, integrated teacher professional development and the mastery of critical teacher ICT competencies.

Teachers' perceptions and expectations

Learning environment characteristics

In total, 42% of the codes were related to environmental characteristics, pointing at subthemes such as: design and instructional remarks, estimated instructional time, etc. (see Table 2). Our learning path and the didactical materials covering 'bacteria collection and growth' was based on the official GO! biology school curriculum, and was designed and developed by recently graduated biology teachers and revised by pre-service teachers and their lecturer. It replaced the traditional teaching materials, usually developed by teachers themselves, as most of them do not adopt commercial textbooks.

Teachers were asked to evaluate the new learning materials (i.e. learning path, lab exercises, worksheets and teaching scenarios); with respect to the way they were designed as well as their ease of use. Teachers' input was used to improve these learning materials that were further used in subsequent quantitative studies. In addition, teacher feedback was also a way to sample data to learn whether the learning materials achieved their instructional objectives, whether they were attractive to learners and sustained their interest. In general, teachers were positive about the materials provided. The required instructional time was judged adequate.

Teacher satisfaction with the learning outcomes

22% of the codes focused on teacher satisfaction with the learning outcomes, resulting from studying in the LMS with learning paths. Teacher opinions were mixed. Four teachers reported that the performance was lower than expected; six teachers did not mention any differences and six teachers reported higher learning results than expected.

"What I really appreciate about learning paths, is the fact they stimulate students to learn and develop essential insights autonomously." [Teacher 2]

"When average students were working collaboratively, they achieved better results than the high performing students, who usually prefer to work alone." [Teacher 9]

"A learning path is particularly suitable for high performing students. It also works for the low performing students, but they need more guidance." [Teacher 5]

Earlier research about secondary education teachers' satisfaction with learning objects, showed positive reactions (McCormick & Li 2005; Kay & Knaack 2008b). In the present study, teachers are satisfied with the learning paths' ease of use, but doubt their adequacy to attain learning outcomes. Earlier research, e.g. De Smet et al. (2012), demonstrated the importance of both ease of use and usefulness in the acceptance of LMS. In addition, Kember (1997) stressed that teacher conceptions influence their teaching approaches, which in their turn have an impact on student learning and ultimately affect learning outcomes. As stated above, some of our teachers holding a teacher-centred belief may have felt insufficiently prepared to work with this learner-centred approach.

Learner characteristics

Liaw, Huang and Chen (2007) emphasized that a key issue to consider when developing e-learning environments, is a good understanding of the target group. De Smet and Schellens (2009) found that teachers make ample use of advanced LMS functionalities; e.g., 6% use the chat module, 10% learning paths, 11% wikis and 14% asynchronous discussion groups. As this study was carried out in a similar context, we can expect related remarks about learning paths, since they are new for most teachers and students. While teachers had to adjust to the new learning tool, students adapted quickly.

"These students grew up with a computer; they are very comfortable with using new tools." [Teacher 4]

"Sometimes they already know what to do before my explanation was finished." [Teacher 6]

Almost all teachers reported the same lesson 'flow': in the beginning learners were very enthusiastic to work on the computer, but after three lessons (out of four) they got bored. Teachers even reported some students were eager to return to a conventional instruction format.

"Some students, who wish to accelerate their studies, prefer lessons where I instruct them. After 3 lessons they said: can you instruct us? We think we will be able to remember it better via conventional instruction." [Teacher 1]

Kay and Knaack (2008b) found that teacher ratings of learning, quality and engagement related to learning materials were significantly correlated with student ratings. Given the mixed feelings of our teachers and an ambiguous relationship between teacher beliefs and learning approaches, it should not be surprising students expressed similar concerns. Wu, Tennyson and Hsia (2010) reported similar findings. They concluded that, the more confident and accustomed students become with online learning within an LMS; the more likely they will expect benefits from using it, foster a positive learning climate, and also be more satisfied.

Conclusion and limitations

In view of our first research question, we tried to find out which conditions at the school and teacher level affect the use of learning paths. At the school level, several problems with the availability and the well-functioning of the ICT infrastructure were reported, sometimes even leading to the conclusion that the use of ICT in the classroom became impossible. Technical support was available to some of the teachers, but the quality differed. Pedagogical support or teacher training courses were almost non-existent. The role of the school principal or school management was mentioned by only two teachers. All these barriers have been identified in earlier research as factors preventing the successful ICT integration in the classroom (Bingimlas, 2009; Tondeur et al., 2008), and lead to the conclusion that the e-capacity (Vanderlinde & van Braak, 2010) of the schools participating in our study is yet not at an optimal level.

To answer our second research question, we especially built on teacher perceptions and expectations about learning paths as an educational tool, related learning outcomes and student characteristics when learning with the LMS/learning paths. According to Liaw et al. (2007), the latter are essential in order to obtain effective e-learning environments. Most teachers were satisfied with the content and the design of the educational materials provided, but had mixed feelings about student learning outcomes. We referred to a potential incongruence between current educational teacher beliefs and the learning approaches deployed in the LMS (Ertmer & Ottenbreit-Leftwich, 2010). Moreover, while teachers had to adjust to the new learning methods, students adapted quickly, but expressed similar concerns as their teachers.

The present study adds to the literature in several respects. First, qualitative research about the use of learning paths within an LMS in a real secondary classroom setting is scarce. Second, this study identified several barriers at the school and teacher level affecting the successful implementation of learning paths. Third, this study explored the key stones to develop successful e-learning material and provides an insight on teacher attitudes and perceptions towards using learning paths as an educational tool, on students' learning outcomes and on learner characteristics that foster learning in an LMS.

Despite the advantages of the authentic research context, this study reflects some limitations. First, we build on teacher perceptions as expressed during interviews, not on their actual behaviour. Second, our research only involved teachers, while students were not consulted. Third, our sample was small and very specific considering the stratification framework being used. Fourth, the expected influence of studying with the learning paths can have been partially confounded due to uncontrolled mixing with additional teaching techniques (as reported by some teachers).

We can conclude that currently, barriers in secondary education prevent teachers from adopting and integrating LMS in their teaching. Given these observations, it is unlikely teachers are ready and willing to adopt innovative teaching and learning approaches based on LMS and/or learning paths; as stated also by the NMC Horizon Report (2014) who doubt major progress on the short term. The implications for policy makers and school leaders are that they need to push the conditions preventing teachers from integrating ICT and LMS within their teaching. Only then will our teachers and learners benefit from technological changes and opportunities.

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6 | General discussion and conclusion

Some parts of this chapter are based on:

De Smet, C., Bourgonjon, J., De Wever, B., Schellens, T., & Valcke, M. (2012). Researching instructional use and the technology acceptation of learning management systems by secondary school teachers. *Computers & Education, 58*(2), 688-696. doi:10.1016/j.compedu.2011.09.013

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Chapter 6:
General discussion and conclusion

Abstract

The general aim of this dissertation was to increase our understanding of how LMS (Learning Management Systems) are used by secondary school teachers, and to examine the design and implementation of learning paths. Based on the theoretical framework, this general aim was broken down into five research objectives (see Chapter 1). This final chapter discusses the results of the different studies reported in this dissertation - as related to the various research objectives and to our eclectic theoretical framework.

In addition, this chapter provides a more general discussion of the study, including the limitations of the different studies and directions for future research. This chapter concludes with a presentation of the implications of this dissertation for theory, research, practice and policy.

Introduction

This dissertation focused on the integrated use of LMS by secondary school teachers. When studying the relevant literature, we noted that, despite the high adoption rate of LMS, little is known about the technological acceptance of LMS (Van Raaij & Schepers, 2008; Sánchez & Hueros, 2010). Moreover, empirical research appeared scarce, especially research relating to secondary education (Kay & Knaack, 2008a). In addition, the selective adoption of certain LMS functionalities such as wikis, discussion forums, or learning paths (De Smet & Schellens, 2009) suggested that teachers have little knowledge of how to design and implement learning activities with these educational tools.

Because we wanted the studies in this dissertation to be relevant to both educational research and theory development, we chose to further investigate learning paths within LMS - and to develop educational materials that are as relevant and as close to currently available instructional materials as possible. A variety of conceptual frameworks were adopted to direct the studies: literature about technology acceptation, cognitive load theory, and the cognitive theory of multimedia learning. Research on collaborative learning and the e-capacity framework were also used to inform our studies. These frameworks built on school-related variables, teacher related-variables and processes, the nature of the design of LMS, or on the ways students study in the context of an LMS. Consequently, five important research objectives were introduced in detail in the introductory chapter. All research objectives were interlinked, and influenced the design of the subsequent empirical studies. We will discuss the objectives shortly below.

The first research objective dealt with the adoption of LMS in secondary education, building on the extended Technology Acceptance Model (or TAM2; Venkatesh & Davis, 2000), which had been used in earlier research to understand and predict LMS acceptance in both non-educational (Ong, Lai & Wang, 2004) and educational settings (Ngai, Poon & Chan, 2007; Sánchez & Hueros, 2010).

The second objective was to research the instructional uses of LMS. We built on research by Hamuy and Galaz (2010) that differentiated between two broad types of LMS functionalities: informational use and communicational use.

Based on the empirical results obtained when answering research objectives 1 and 2, research objective 3 investigated whether the way learning paths are designed and implemented has a beneficial impact on learning outcomes. This third research objective was inspired by Kay and Knaack (2008a), who drew our attention to the potential of research on the design (how learning objects are bundled and/or sequenced into learning paths) and implementation (how learning paths are undertaken individually or collaboratively) of LMS within secondary education. This type of research and research on related student performance outcomes is scarce (Nurmi & Jaakkola, 2006). The research question built on the CTML guidelines (Mayer, 2003, 2005) and on research about collaborative learning. Gender was considered as a critical moderator, given the focus on STEM education (science, technology, engineering, and mathematics).

Since the study researching objective 3 was less conclusive about the beneficial effects of collaborative learning, we decided to investigate this particular aspect in greater detail. Possible causes explaining the limited effect of collaborative learning were, amongst others: group composition (Resta & Laferrière, 2007), the role of gender within group composition (Johnson & Johnson, 1996), and the reported tendency of females to be less active in certain group settings (Felder, Felder, Mauney, Hamrin, & Dietz, 1995). To investigate research objective 4, we conducted a quasi-experimental study focusing on the differential impact of learning paths and conventional instruction, considering a collaborative or an individual learning approach and variations in group composition. Given that this research also took place within a STEM education context, and the fact that both design decisions and implementation features (group setting and group composition) were found to influence learning outcomes based on gender (Harrison & Klein, 2007), gender was considered again an important moderator.

Research objectives 3 and 4 gave little attention to the ways teachers perceive and use LMS and the learning paths. Therefore, research objective 5 investigated how the perceived conditions at school and teacher level affected the use of learning paths, and how these conditions are related to the expected outcomes. This qualitative study was inspired by the e-capacity framework of Vanderlinde and van Braak (2010); the work of Liaw and Huang (2007); Liaw, Huang, and Chen (2007); and Liaw (2008).

We reiterate the five research objectives put forward in the first chapter:

Research objective 1 (RO1): Research the technology acceptation of LMS by secondary school teachers, based on a conceptual acceptance model including: perceived usefulness, perceived ease of use and subjective norm, personal innovativeness towards IT, internal ICT support, and experience.

Research objective 2 (RO2): Examine instructional use, and more specifically the relationship between informational use and communicational use, and the question of whether informational use is required to foster the adoption of communicational use within an LMS.

Research objective 3 (RO3): Investigate whether a particular design and implementation of learning paths has a beneficial impact on learning outcomes, and gender as a moderator.

Research objective 4 (RO4): Undertake a comparative study of learning paths and conventional instruction in a learning management system, considering a collaborative or individual learning approach, with variations in group composition and gender as important moderator.

Research objective 5 (RO5): Report on teacher perception of learning paths usage within an Learning Management System (LMS), and its relation to conditions at the school, teacher and student level, and how this affects the adoption of learning paths.

Overview and discussion of the main results on the basis of research objectives

Teachers' technology acceptance and instructional use of LMS in secondary education (RO1 and RO2)

The first research objective deals with technology acceptation of LMS by secondary school teachers. The second objective further examines the instructional use of LMS. As described in Chapter 2, a teacher questionnaire was administered to 505 secondary school teachers in 72 schools. The theoretical model was based on TAM2 (Venkatesh & Davis, 2000), whose components 'perceived usefulness', 'perceived ease of use', and 'subjective norm' were expanded with 'personal innovativeness towards IT' (Agarwal & Prasad, 1998), 'internal ICT support' (Tondeur, Van Keer, van Braak & Valcke, 2008) and 'experience' (Sun and Zhang, 2006). The model also took into account self-reported LMS use (Schillewaert, Ahearne, Frambach, & Moenaert, 2005; van Raaij & Schepers, 2008), conceptualised as 'informational use' and 'communicational use' (Hamuy & Galaz, 2010).

For both research objectives 1 and 2, we developed research instruments based on an extensive literature review. Exploratory factor analyses confirmed the variable structure put forward in the instrument design. The hypothetical relationships between the variables were tested on the base of path analysis.

The entire model helped to explain 36% of the variance in informational use and 26% of the variance in communicational use. These research findings contribute to the literature in a number of ways:

First, the instructional use of LMS by secondary school teachers was further explored and refined. The operationalization of the instructional use of an LMS into informational use and communicational use appeared to be valid. As hypothesized, informational use was found to be positively associated with communicational use.

Second, all hypotheses constituting the traditional TAM2 framework were reconfirmed in the context of studying LMS: perceived usefulness and perceived ease of use help to explain the informational use of LMS, leading to the conclusion that a secondary school teacher will take into account the usefulness and ease of use of an LMS in their decision to use it. As expected, ease of use influences the perception of LMS usefulness, which makes ease of use an important starting point if we want teachers to use LMS. Subjective norm appeared to be a significant factor in determining perceived usefulness. Internal ICT support positively affects subjective norm, but does not significantly affect informational use. This finding implies that supporting teachers at the school level will not directly influence their personal use of LMS, but may impact the opinions about LMS of the teachers' important others. More importantly, as already indicated by Tondeur et al. (2008), the impact of internal (school) ICT support suggests that school-level variables are important for understanding technology acceptation. This suggestion was reflected in Chapter 5 of this dissertation, which reported on conditions at the school and teacher level (or the e-capacity of the schools) that affected the use of LMS. Teachers referred (in Chapter 5) to the following critical missing conditions: robust access to technology and infrastructure, effective and available technical and pedagogical support, and the need for mastery of critical teacher ICT competencies. Another interesting finding of our theoretical model is the positive association of personal innovativeness with perceived ease of use. This suggests that innovative teachers are more easily convinced of the ease of use of LMS. On the other hand, the impact of innovativeness on usefulness was lower, meaning that being innovative does not automatically result in a positive belief about a system's performance. This is also confirmed by the relation between personal innovativeness towards IT and communicational use. Being innovative is clearly not enough for one to start using an LMS for communicational use. Experience significantly affects perceived ease of use, but a stronger relationship was found between experience and informational use.

Third, the study focused on the acceptance of LMS by secondary school teachers, an understudied group. This lack of interest by researchers in the past is all the more surprising, given the large potential of LMS and learning paths at this educational school level.

The design and implementation of learning paths in a LMS (RO3)

As discussed in Chapter 3, we investigated whether additional investment in the design and implementation of learning paths within STEM-education has a beneficial impact on learning outcomes. To research this goal, we built on three literature strands. Our research about the design of learning paths, or the way they are visually represented, is based on the Cognitive Load Theory (Sweller, 1988, 1994; Sweller, van Merriënboer & Paas, 1998; van Merriënboer & Sweller, 2005) and the Cognitive Theory of Multimedia Learning (Mayer, 2001, 2003, 2005). Cognitive Load Theory (CLT) is an instructional theory that focuses on the human cognitive architecture and has clear consequences for the design of instructional and learning materials. The Cognitive Theory of Multimedia Learning (CTML) does not only build on CLT's cognitive architecture, but also looks explicitly at design principles for multimedia learning. Next, our instructional design of the learning paths was based on the field of Computer Supported Collaborative Learning (Dillenbourg, Baker, Blaye & O'Malley, 1996). Gender was considered a critical moderator, given the clear gender gap within STEM-education and the fact that both design decisions (Super & Bachrach, 1957; Wai, Lubinski, & Camilla, 2009) and group setting can influence learning outcomes based on gender (Harrison & Klein, 2007).

Two alternative versions of a learning path were created. The first learning path (hereinafter abbreviated as TSPW) consisted of multimedia learning objects that build on Text, Schemes, Pictures, and Web-based exercises. A second version of the same learning path (abbreviated as MGL) was developed by applying Mayer's Multimedia Guidelines (2003) and by adding advanced organizers in order to help organize unfamiliar content (Ausubel, 1960, 1968). Students worked either individually or collaboratively, leading to a 2 x 2 factorial research design. They were offered knowledge tests at three seperate moments: a pre-test, a post-test (immediately after completion of the learning path), and a retention test (one month after completion of the learning path). MLwiN software was applied (Centre for Multilevel Modelling, University of Bristol) to analyse the hierarchical data (Nezlek, 2008, Rasbash, Steele, Browne, & Goldstein, 2009) and followed a two-step procedure to analyse the effects of three independent variables (design decisions, group setting, and gender) on the dependent variable (learning outcomes). Instructional support - in the form of teacher scenarios - was provided to scaffold or script the collaborative-learning process (Kollar, Fischer & Hesse, 2006). The use of these scenarios (based on existing lesson preparation templates) had two advantages: 1) Flemish teachers are used to work with these scenarios as part of their daily work routine, and 2) they guaranteed the same learning opportunities for all students, over all research conditions.

The three highest knowledge scores on the post-test were attained by males and females following a MGL learning path within an individual setting and by males in a collaborative setting. However, only the results for both males and females following the MGL learning path in an individual setting were found significant. These observations lead to the following conclusions: firstly, a design decision (i.e. optimizing a learning path with Mayer's Guidelines (2003) leads to better knowledge scores; secondly, an implementation decision (i.e. students who collaborate) does not help students within an collaborative setting to outperform students

within an individual setting. To study the impact of gender, our third independent variable, we made a distinction between males and females. For males we hypothesized that spatial ability (Wai, Lubinski, & Camilla, 2009) would play a critical role, as males are expected to benefit most from a learning path, optimized with Mayer's (2003) guidelines (MGL learning path). This hypothesis was confirmed, but only for males following the MGL learning path in the individual setting. For females we hypothesized, in view of the group diversity literature (Curşeu, Schruijer, & Boroş, 2007; Curşeu & Sari, 2013) and the positive impact web-based collaborative inquiry has on girls (Slotta & Linn, 2009; Raes, Schellens, & De Wever, 2014), that learning outcomes would outperform when girls work collaboratively, however no conclusive evidence was found to accept this hypothesis.

We acknowledge that group diversity literature and the literature on collaborative learning can shed new light on our results, and may present arguments that we did not take into account within this study, as discussed in Chapter 3. In their meta-analysis about studies focusing on collaborative learning and the use of educational technology, Resta and Laferrière (2007) refer to evidence that was found in favor of collaborative learning when groups are heterogeneous, including gender (see also Johnson & Johnson, 1996), but also to the tendency of women to be less active in learning groups (see also Felder et al., 1995). Curşeu, Schruijer, and Boroş (2007) and Curşeu and Sari (2013) postulated that gender variety has a positive outcome on group cognitive complexity, and that mixed-gender groups achieve better results. However, as gender diversity can also be differentiated as gender separation and gender disparity, negative influences on group effectiveness may have taken place. In addition, the population under study in the work of Curşeu, Schruijer, and Boroş (2007) and Curşeu and Sari (2013) were on average 20 years old; our students were, on average, 15 years old. This is an important difference that should be taken into account, as age plays an important role, and the female advantage is almost exclusively reported in junior, middle, and high schools (Voyer & Voyer, 2014).

The way groups are structured and promote interaction can also make a difference. Barron (2003), for example, points to the importance of how collaborative projects are structured; they can lead to different ways of interaction among students (e.g. students can choose methods like the divide-and-conquer approach). Following Kreijns, Kirschner, and Jochems (2003), the key to successful collaborative learning is social interaction; the way group members socially interact influences the collaboration positively or negatively. Even more, according to Hooper and Hanafin (1991), social interaction within a group is believed to be more important than group composition. Thus, several negative influences on collaborative learning may have played a role within our research, where membership in a group was formed randomly. Despite our extensive teacher scenarios and comprehensive briefing of the teachers, these factors can explain, in combination with the strong impact of the way learning paths are visually presented, why the collaborative conditions underperform within this research. In addition, in Chapter 5 of this dissertation, we also referred to a possible conflict between teacher beliefs and teaching approaches (Ertmer, 1999, 2005; Inan, Lowther, Ross, & Strahl, 2010). The assumption that the teacher-centred belief relies upon, is the preference of the teacher to be at the centre of the

learning process and to focus on knowledge-reproduction using traditional teaching methods (e.g. lecturing), whereas a learner-centred belief implies learning as a partnership between the teacher and the student and allows active student participation and construction of knowledge through student-centered activities like collaborative learning (Inan et al., 2010). In this dissertation, teachers taught with learning paths that build upon student-centered activities (i.e. collaborative learning). In that respect, some of our teachers adhering to a teacher-centred belief were confronted with an incongruent instructional approach, which may have created significant obstacles to the use of the LMS and of the educational material provided (Ertmer, 1999).

A comparative study of learning path
and conventional instruction in a LMS (RO4)

In chapter 4, we conducted a comparative study between learning paths and conventional instruction, considering a collaborative or individual learning approach, variations in group composition, and gender as an important moderator.

From a theoretical perspective, the potential benefits of learning paths build on (1) the assumptions related to the Cognitive Theory of Multimedia Learning (Mayer, 2001, 2003, 2005) and (2) the assumptions related to instructional technology conceptions. The beneficial impact of computer-based instruction over conventional instruction was based on research by Kulik, Bangert and Williams (1983); Christmann, Badgett, and Lucking (1997); Jenks and Springer (2002); and Li and Ma (2010). Both research objectives 3 and 4 are grounded in the CTML framework, directing instructional design of multimedia materials and presenting practical guidelines to design multimedia learning materials. When designing and researching the collaborative learning setting (using scripted teacher scenarios), we build, as stated above, on the available research in the field of Computer Supported Collaborative Learning. Since the results of the study in Chapter 3 were less conclusive as to the beneficial effect of collaborative learning, we had to take into account mediating variables related to group composition (Resta & Laferrière, 2007) and the role of gender within group composition (Johnson & Johnson, 1996; Felder et al., 1995). As a result, in Chapter 4 we researched the relation between group setting and group composition and the expected influence of gender on learning outcomes.

The study discussed in Chapter 4 was set up, building on the experimental learning path about bacteria collection and growth discussed in chapter 3, given the positive evaluative perceptions of both teachers and students. Some small adjustments were made, based on their feedback. Students were presented with knowledge tests at three separate moments: a pre-test, a post-test, and a retention test. A multilevel model was developed where the knowledge tests were defined as the first level, students as the second level, classes as the third level, and schools as the fourth level. MLwiN software (Centre for Multilevel Modelling, University of Bristol) was used to analyze the hierarchical data structure (Nezlek, 2008; Rasbash, Steele, Browne, & Goldstein, 2009). Subsequently, a two-step procedure was followed to analyse the effects of four

independent variables (instructional method, collaborative/individual setting, group composition, and gender) on the dependent variable, i.e. learning outcomes.

We expected students studying via a learning path to attain higher learning outcomes than students studying in a conventional learning setting. This hypothesis was confirmed (on the retention test), allowing the conclusion that learning paths can help to improve learning outcomes as compared to conventional instruction. Our second expectation was not confirmed: students who study learning paths in a collaborative way did not outperform students within an individual setting. Thus, in line with the previous chapter, the impact of collaborative learning was less obvious. Next, when gender and group composition were taken into account, a remarkable finding was put at the centre: more specifically, the presence of a girl was found to be beneficial for boys in a mixed-gender group, whereas girls themselves performed better when working alone. A similar difference between boys and girls was observed when researching the performance of mixed-gender groups in relation to same-sex groups: mixed-gender groups were found to be more beneficial for males with respect to their outcomes, while females scored better in same-sex groups. Finally, we assumed that girls would outperform boys with respect to their outcomes, independent from the instructional method used. This hypothesis was rejected when comparing students studying via a learning path versus conventional instruction, but confirmed for girls working individually with a learning path versus boys in the same condition.

In our discussion on Chapter 3 (see above), we examined the underperformance of collaborative learning in relation to gender, group structure, group diversity etc. (e.g. Johnson & Johnson, 1996; Barron, 2003; Curşeu, Schruijer, & Boroş, 2007; Curşeu & Sari, 2013), but we did not discuss the outperformance of the individual setting compared to the collaborative setting. In this respect, Kirschner (2001) and Kreijns, Kirschner, and Jochems (2003) discussed several instructional techniques that can help group members socially interact in ways that enhance collaboration. They suggest providing epistemic tasks within a group (e.g. describing, explaining, arguing, critiquing, etc. in the context of a discourse); using direct approach methods like the Jigsaw technique (group members have access to different data, which, like the pieces of a puzzle, need to come together; Brown, 1992), or apply conditions that enforce collaboration within a group, e.g. positive interdependence (success depends on the participation of all the members; Johnson, Johnson & Holubec, 1998) and individual accountability (each group member needs to achieve the groups' goals; Johnson, Johnson & Holubec, ibid). Use of these techniques could have promoted interaction within the group and thus resulted in better learning outcomes. We also noted that our findings show a superiority of studying individually with a learning path on retention test scores, which is in line with previous research by Christmann, Badgett, and Lucking (1997) and Lockee, Moore, and Burton (2004). In their meta-analysis, Kulik, Bangert, and Williams (1983) noticed increased scores on retention tests, even several months after the completion of the instruction. However, they concluded that these effects were not as clear as the immediate effects on the post-test. Similar results were reported in a later study (Kulik & Kulik, 1991), where they examined 20 studies on follow-up

examinations. On the other hand, within the literature there is evidence for what is known as 'the testing effect', which refers to the tendency that someone's long-term retention of knowledge is strengthened by testing it. Dirkx, Kester, and Kirschner (2014) recently confirmed this effect as they found that secondary school students benefited from testing "not only the retention of facts from a mathematics text, but also the application of the principles and procedures contained in that text" (p. 361).

Besides the underperformance of collaborative learning, the role of gender remains an important point of discussion in Chapter 4. In the learning path condition, girls outperformed boys in the individual setting and in same-sex groups. In addition, we found evidence that boys are more productive in mixed-gender groups than in same-sex groups. This suggests that males benefit from the presence of a female when working collaboratively, whereas females benefit most from same-sex groups when working collaboratively. This is in line with the observations of Felder et al. (1995) that girls in same-sex groups perform better than within mixed-gender groups. As already indicated, Voyer and Voyer (2014) remarked that age plays an important role, as the female advantage is almost exclusively reported in junior, middle, and high school.

Other arguments besides the micro-level can put forward alternatives to close the gender gap. Driessen and van Langen (2013) observed and discussed three categories of intervention strategies to deal with the gender gap. The first is referred to as the pedagogic-didactic measures (James, 2007) category. This strategy aims to train teachers to deter gender stereotypes when using computers, through the use of integrated approaches or by anticipating an expected learning style. The second category, relating to sociocultural interventions (Martino, 2008), tries to stimulate the motivation and interest of the gender in question, e.g. a program that wants to stimulate girls to study STEM subjects. The very limited success of these programs is recently illustrated by research from Laurijssen and Glorieux (2014), which revealed that girls in Flanders still choose the same fields of study as they did in the fifties. It was found they prefer fields like social sciences and law, but avoid engineering or veterinary sciences. A third category includes organizational interventions (Buchmann, DiPrete, & McDaniel, 2008), e.g. experiments with single-sex classes. Driessen and van Langen (2013) conclude that almost no positive effects of these interventions were reported nor achieved. More recent research (Fullan, 2010) even suggests going beyond the variable 'gender' to explain potential differences in learning impact. Studies of De Backer, Van Keer, and Valcke (2012) suggest that groups differ in the way they regulate each other's cognitive processing. The same research also suggests that other types of collaborative learning could be adopted (e.g., reciprocal peer-tutoring) to guarantee more focused (meta)-cognitive processing. Gielen and De Wever (2012), building on research of Nadler (1979) into the effects of feedback on task group behavior, noted that the quality of a wiki product improved when students received feedback on an individual basis by their peers. This suggests that individual feedback of peers in a group setting improves the performance of its members. By conducting this type of research and looking into students' knowledge elaboration process during collaboration, it is hoped to find a solution that improves the

individual learning achievement of both female and male students when they work together. (Ding & Harskamp, 2006).

A qualitative study on learning and teaching with learning paths in a LMS based on teacher perceptions' (RO5)

In chapter 5, we report about teacher perceptions of learning path usage within a Learning Management System (LMS), how this relates to conditions at the school and teacher and student levels, and how this affects the adoption of learning paths as an educational tool. This qualitative study was closely linked to the quantitative studies reported in chapter 3 and 4, as the interviews were set up after teacher involvement in these studies. We adopted the e-capacity framework of Vanderlinde and van Braak (2010) and conceptions derived from the research about user perceptions of e-learning systems (Liaw & Huang, 2007; Liaw, Huang & Chen, 2007; Liaw, 2008) to develop our theoretical base. Data was gathered by presenting twenty pre-defined questions to teachers from 13 schools, following a semi-structured interview protocol (Taylor & Bogdan, 1998). The software package Nvivo was used for segmentation (identifying meaningful units) and categorization of the data; NVivo matrices were used to structure the coded units in the interviews.

Our goal was to identify how conditions at the school and teacher level affect the use of learning paths. At the school level, several problems with the availability and the technical functioning of the ICT infrastructure were reported, sometimes even leading to the conclusion that the use of ICT in the classroom was unfeasible. Technical support was available to some of the teachers, but its quality varied. Pedagogical support or teacher training courses were almost non-existent. These barriers led to the conclusion that the e-capacity (Vanderlinde & van Braak, 2010) of the schools participating in our study was yet not at an optimal level. To determine the impact of teacher level variables, we built on questions that invoked teacher perceptions and expectations about learning paths as an educational tool, on student related learning outcomes and on student characteristics when learning with LMS/learning paths. We found most teachers were satisfied with the content and the design of the educational materials provided, but reported mixed feelings about student learning outcomes. We also referred to a potential incongruence between current educational teacher beliefs and the learning approaches deployed in LMS (Ertmer & Ottenbreit-Leftwich, 2010). Moreover, while teachers had to adjust to the new learning methods, students adapted quickly; however, they expressed concerns similar to their teachers'. As a result, we concluded that barriers in secondary education prevent teachers from adopting and integrating LMS in their teaching, and we therefore doubt that teachers are ready and willing to adopt innovative teaching and learning approaches based on LMS and/or learning paths.

But, considering the fact we only studied conditions at the school and teacher levels, we have to acknowledge that our focus was limited to the two inner 'circles' of the e-capacity model discussed in this dissertation (Vanderlinde & van Braak, 2010). As a result, we did not take into account the potential impact of leadership, the possible participation of teachers and decision

making process in schools, or the influence of collegial relations and collective practice. These are all important factors affecting the use of ICT, as described in the 'school improvement conditions' circle by Vanderlinde and van Braak (2010). In addition, schools are part of society, and thus under the influence of factors such as national and international policies and subject to debate on economic, political, and social grounds (Cuban, 1990; European Commission, 2013).

Overview and discussion of the main results on the basis of the eclectic theoretical framework

In the previous section, we discussed the results on the base of our research objectives. In this section we discuss them on the basis of our graphical representation of the eclectic theoretical base (Figure 1) adopted in the studies of this dissertation as presented in the introductory chapter. This will help to go beyond the isolated discussion of research findings within the boundaries of the individual studies. In addition, the discussion also centers on the theoretical framework itself and questions its adequacy, generalizability and whether alternative structures could/should be considered. Given the interrelated nature of processes and variables of this framework, certain discussion topics are recurrent in nature.
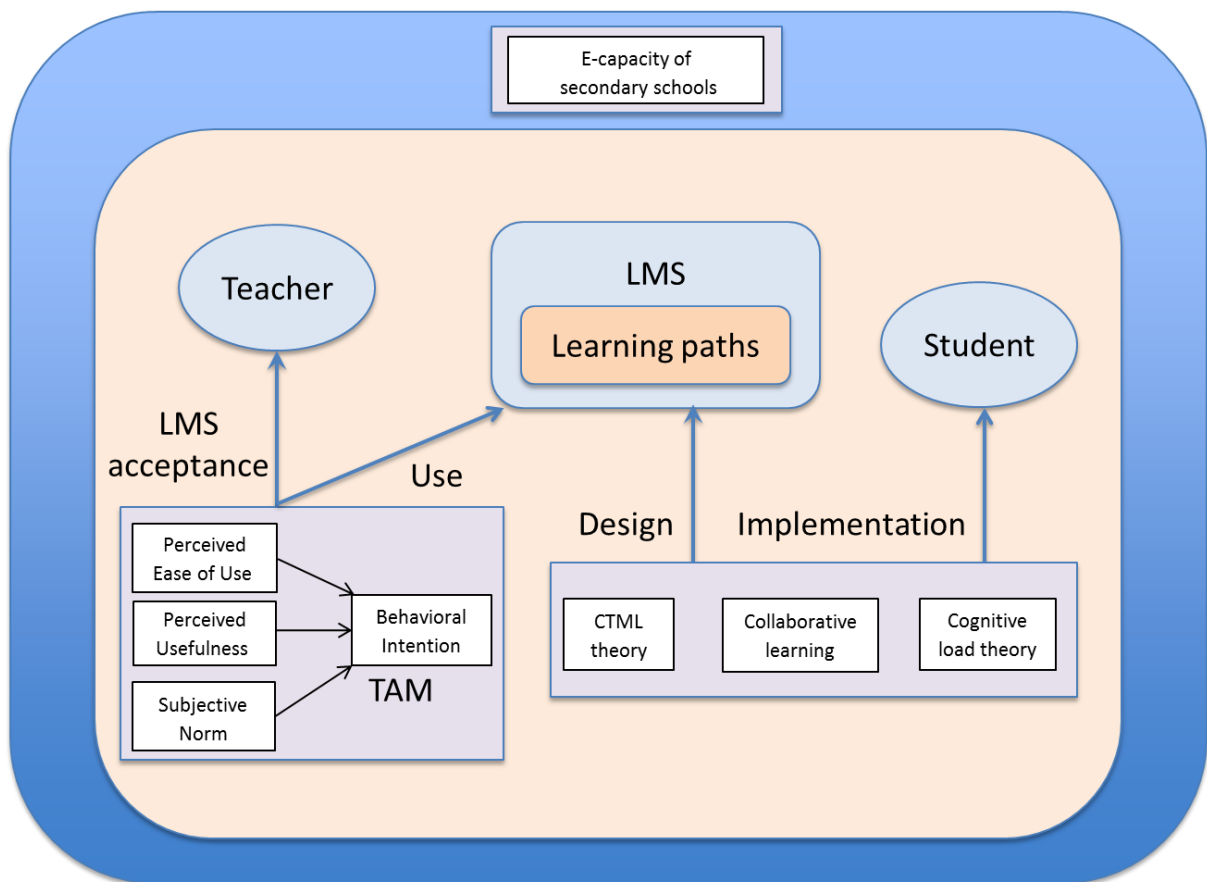

Figure 1. Graphical representation depicting the eclectic theoretical base adopted in the studies of this dissertation as presented in the introductory chapter.

Discussion on the use and acceptance of LMS in our model

In Chapter 2, we discussed the LMS 'acceptance' of teachers by focusing on their behavioral intention to use LMS. We adopted the TAM2 model (Venkatesh & Davis, 2000), a latter version of TAM, given the international recognition the model gained within the literature about technology adoption (van Raaij & Schepers, 2008). Our choice for TAM2 (a decision made in 2008) in favor of another widely accepted model such as the Unified Theory of Acceptance and Usage of Technology (or UTAUT; Venkatesh, Morris, Davis, & Davis, 2003), was partly based on earlier research by van Raaij and Schepers (2008). They recognized UTAUT's higher proportion of variance accounted for (r-squared), leading to explain 70% of the variance, but warned the model resulted in less parsimonious models than its predecessor. Teo (2011) added to this, UTAUT had only been leading to these results, when it was applied in large organizations in a business environment. In their meta-analysis of UTAUT, Dwivedi, Rana, Chen and Williams (2011) criticized the over-exploitation of TAM, leading to the development of alternative theories and models on technology adoption, but they also recognized that "*it is difficult to demonstrate that UTAUT is replacing TAM in empirical studies as there is no review of previous empirical studies that have utilized UTAUT. Also, there is no study that has surveyed or reviewed performance of UTAUT subsequently – so, there is a lack of information regarding reliability and consistency of performance of this theory in different situations*" (p. 156).

Other models, such as the Information Systems Success Model (ISSM) by Delone and McLean (1992, 2003), could have been suitable to study technology adoption. This ISSM model provides a comprehensive understanding of how information systems are used, based on the following six dimensions: system quality, information quality, service quality, system use, user satisfaction, and net benefits. Roca, Chiu and Martinez (2006) for example, extended TAM partly with the ISSM variables 'information quality' and 'system quality'. They concluded information quality was an important factor influencing users' satisfaction and thus positively influencing their interest in using the e-learning system. In this respect in future research, extending our TAM2-model with the ISSM variables 'information quality', 'service quality' and/or 'system quality', could be an interesting option to further explore LMS usage.

The latter discussion pushes our thinking about the TAM model in the overall theoretical framework in the direction of the e-capacity model (Vanderlinde & van Braak, 2010). This e-capacity model introduces interesting additional variables at the school level. Except from 'Internal ICT support', no other variables at the school level are now considered within the TAM2 framework. The concept of 'subjective norm' that has been identified as a relevant variable associated with types of LMS use, can be linked to the role and position of individual teachers in a team (Ertmer & Ottenbreit-Leftwich, 2010). This school team could support and/or enhance individual use by adopting a shared school vision about LMS usage (Devolder, Vanderlinde, van Braak & Tondeur, 2010).

Next, ICT-related teacher conditions and ICT related school conditions, identified in the e-capacity model, also push the TAM-model. The latter suggests that we should expand the TAM2-model with variables that go beyond a teacher's individual level to explain his/her behavioral

intention to accept LMS. Our research results in chapter 5 indicate the relevance of such an extensions: a reliable and accessible ICT infrastructure; qualitative and available technical and pedagogical support services; and extensive teacher professional development courses, resources and activities that are aimed to help teachers possess the required knowledge, skills and attitudes to use and integrate LMS usage. As a result, in Figure 2 we add school team, ICT infrastructure, teacher professional development and technical and pedagogical support to our framework that could be used in future research to explain LMS adoption.
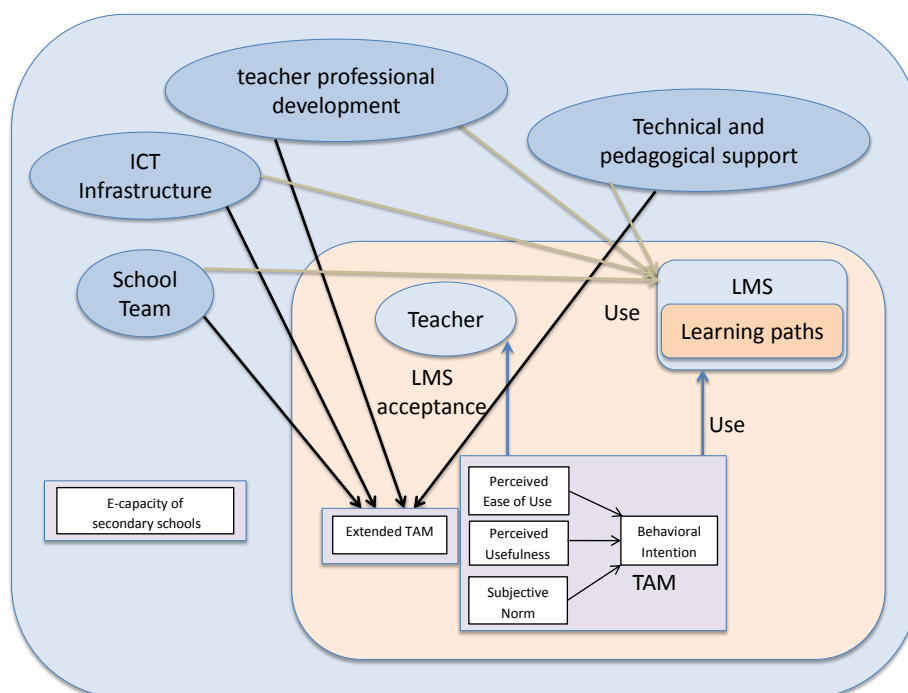

Figure 2. Graphical representation depicting the potential extended TAM2-model.

Discussion on the design of LMS components

There is abundant literature about the design of multimedia. We based part of our theoretical framework on authoritative theories that present evidence-based guidelines to develop learning objects in ICT-environments. In particular, the Cognitive Load Theory (CLT), and the ensuing Cognitive Theory of Multimedia Learning (CTML) were discussed in this dissertation to guide the instructional design of effective multimedia use in view of developing and presenting learning paths. The CTML (Mayer, 2003, 2005) builds on a set of empirically established principles like the modality principle (graphics are better supported with audio as compared to text), the multimedia principle (word and graphics lead to better learning outcomes than words alone) etc. Recently, numerous studies on instructional design have led to the further refinement of these and related design principles, e.g. the "expertise reversal effect" (Wetzels, Kester, & Van Merriënboer, 2011). The findings from these authors suggest that the effectiveness of design

principles depend on the level of prior knowledge, and point to the fact that these levels of prior knowledge can be responsible for contradicting findings in design principles. Over time, Mayer who can be considered the founding father of CTML, did also update his own multimedia guidelines; e.g., by developing the Cognitive-Affective Theory of Learning with Media (CATLM; Moreno & Mayer, 2007). CATLM focuses on metacognitive, affective, and motivational constructs (Mayer, 2014), and expands the cognitive theory of multimedia learning (Mayer, 2003, 2005) to media such as virtual reality and case-based learning environments.

In general, the most prominent discussion found in the learning objects (the building blocks of learning paths) design literature, also applicable to the research presented in this dissertation, concerns the "granularity" (i.e. the scope, or how much should be included in learning objects) and the "sequencing" (how do we combine) of learning objects (Wiley, 2000; Kim, 2009). Regarding the granularity level of learning objects, Wiley (2000) refers to the Learning Technology Standards Committee's definition of learning objects, which even allows to view an entire curriculum as a learning object, but he recommends to use granularity levels that are not too high neither too low. Building on literature review, Kim (2009) is more specific and suggests five granularity levels: the first level (assets) contains raw medium or some text, the second level (combined media) consists of text and other media (pictures, audio, animation, etc.), the third level (unit) includes several combined media and other components (a learning objective, content, assessment with media), the fourth level (a lesson or module) comprises a number of units, and finally the fifth level can be made up of several modules. According to Kim (2009), researchers do not agree on the optimal level of granularity, as the lowest levels are perceived as being "too small to contain a context for effective learning" (p. 27), although they offer the advantage of reusability. The highest levels on the other hand, are preferred when learners are involved in more complex learning tasks. Following Kim's granularity levels, the learning path in this dissertation could be situated on the fourth level (4 lessons on the bacteria topic). Given the positive feedback of the teachers as described in Chapter 5 on our bacteria learning path, and the fact there is no consensus on the 'right' granularity level among researchers (Wiley, 2000; Kim, 2009), we can assume the granularity level in this dissertation was about right.

Regarding the sequencing of learning objects, several instructional design theories formulated sequencing guidelines (Wiley, 2000). Following Reigeluth's Elaboration Theory (1999), the impact of sequencing depends on 1) the strength of the relationships among the topics and on 2) the size of the course. When the content to be learned is small and the topics are not related, learners can master the content when sequencing is not provided. In our studies on the biology bacteria learning path as described in Chapter 3 and 4 (which was based upon the official GO! biology curriculum), there is a strong relationship among the topics, because the understanding of a certain learning step is required before students proceed to the following learning step. Next, the size of our course requires sequencing in order to help the students to organize the content logically and meaningfully. This was reported several times by teachers in the interviews as described in Chapter 5.

It seems, nor the granularity level of learning objects, nor their sequencing, helps dealing with the design process of complex learning. In this respect, van Merriënboer and Kirschner (2007) stress that design should be based on a holistic approach, rather than reducing a complex system to simpler elements. In other words, we should go further than merely applying design guidelines. Based upon van Merriënboer's 4-Component Instructional Design model, van Merriënboer and Kirschner (2007) formulated ten activities that can be carried out when designing learning material. More concrete, the first three steps consist of the development of a series of learning tasks that serve as the body of the course. Next, the following three steps focus on identifying the knowledge, skills, and attitudes that are required to perform the learning tasks. The last steps deal with handling procedural information, cognitive rules and prerequisite knowledge. Following these learning steps, van Merriënboer and Kirschner (2007) state we can avoid three commonly cited design problems: compartmentalization (e.g. make a separation between declarative and procedural knowledge), fragmentation (breaking a whole into small parts) and the transfer paradox (what works best for isolated objectives, might not work for integrated objectives). It is clear that an atomistic design - as applied in our dissertation - is subordinated to a holistic approach as presented by van Merriënboer and Kirschner (2007). However, as recognized by Wiley (2000), "reality dictates that financial and other factors must be considered" (p. 12). Bearing in mind the amount of time and efforts we invested in the design and development of 4 lessons, we doubt we can expect the same efforts from individual teachers, especially considering the continuous technological changes (see apps and tablets use in education) and the continuous modifications of the curriculum. To conclude, given our focus on a real classroom setting (see further), we recognize that adopting a holistic approach might be superior, but is not realistic to be adopted by the average secondary school teacher to create his learning materials. In this respect, we advise future research to build on learning materials provided by educational publishers or other professionals in the field and to look for sustainable technologies to develop learning paths.

Collaborative learning was presented as a particular design element in our theoretical framework. Collaborative learning theory has already been discussed in detail in the previous section (within this chapter), in our review to introduce research objectives 3 and 4. In our research, we included additional variables helping to refine our collaboration approach. In this dissertation, both literature on group composition (Resta & Laferrière, 2007), gender diversity (Curşeu, Schruijer & Boroş, 2007; Curşeu & Sari, 2013) and instructional techniques to structure the social interaction within a group (Barron, 2003; Kreijns, Kirschner, & Jochems, 2003) were adopted to explain/predict the (under)performance of particular learners in a collaborative learning setting. This helps to understand why girls outperform boys in the individual setting and in same-sex groups, but not in mixed-gender groups where additional research is required. This also introduces interesting additional theoretical discussions.

For instance, in their meta-analysis based on a sample of 184 articles comparing single-sex education (SS) with coeducational (CE) schooling for a wide range of factors (e.g. student outcomes, performance on mathematics, attitudes etc.), Pahlke, Hyde, and Allison (2014) found

ambiguous results when researching differences on students' mathematics performance between SS and CE schooling for girls and boys. More specifically, in studies controlling for selection effects (e.g. random assignments of students to either the SS or CE schooling condition); the effect size was close to zero. Studies that did not control for selection effects, reported a medium effect size. Taking into account all factors, no substantial advantages of SS schooling versus CE schooling was found. As a result, they concluded future research should only be based on controlled studies (using random assignment and controlling for selection effects), given the diverse opinion and a lack of consensus on the available evidence among researchers. However, in our opinion, studies controlling for selection effects alone will not be able to provide an answer for the differences found. In the governing body where our research took place (GO! is one of the three dominant that sets up schools in Flanders, the Dutch speaking area of Belgium), coeducational schooling is obligated. In this respect our study adds to the discussion as an authentic setting was used. As discussed earlier, future research (e.g. Fullan, 2010) will have to invest in other variables than 'gender', e.g. meta-cognition strategies can help group members socially interact in ways that enhance collaboration and elaborate knowledge (Ding, 2009; Fullan, 2010).

Discussion on the implementation of learning paths

In this dissertation, in order to explain successful LMS integration, we focused on school, teacher and student variables. Unfortunately, and except from the learning outcomes, all additional initiatives undertaken to research or consult the students were not followed by the teachers, who reported time constraints as the main reason (e.g. our evaluation forms on learning paths were not completed). As a result, we took student participation (see Table 1, Chapter 5) indirectly into consideration when focusing on learning environment characteristics as described by Liaw and Huang (2007), Liaw, Huang and Chen (2007) and Liaw (2008). Next we focus on the two inner circles (i.e. ICT related school conditions and ICT related teacher conditions) of the e-capacity framework (see Figure 1 in Chapter 5) of Vanderlinde and van Braak (2010). By doing so, school variables and teacher variables were studied directly, but also somewhat in isolation. We will now elaborate on the school, teacher and student variables in relation to using learning paths within the LMS.

Reflecting on the role and impact of school conditions in our theoretical framework, the importance of ICT support has becomes very clear in both Chapter 2 and 5. This was already suggested above, when discussing a potential extension of the TAM-model in relation to LMS acceptance and usage intention. In Chapter 2, we found no direct relation between ICT support and informational LMS use, but our research confirmed a strong association via subjective norm on (the for the teachers) important others, a finding which was also reported in prior research by Tondeur, Van Keer, van Braak, and Valcke (2008). This suggests that the 'buzz' in the teacher staffroom is more important than we would suspect at first glance; thus reinforcing the position and role of school level variables; e.g., in view of the 'subjective norm'. More specifically, having

colleagues who are enthusiast to tackle new challenging approaches is contagious (Devolder, Vanderlinde, van Braak & Tondeur, 2010). Recent research by Uluyol and Sahin (2014) argued that the usefulness of an approach is believed to increase a teachers' intrinsic motivation, while the encouragement and support from their students, colleagues, school leaders and ICT coordinators, increases their extrinsic motivation. As mentioned above, we therefore added 'school team' to our revised TAM-model (see Figure 2).

Following the same line of reasoning, we also express strong concerns about the teachers' insufficient technical support, and almost no pedagogical support (see Chapter 5). As a result, we concluded that a lack of technical and pedagogical support, is one of the barriers that prevent teachers from adopting innovative teaching. Other barriers were, amongst others problems with the availability and the technical functioning of the ICT infrastructure and the fact that teachers were not aware about the presence of an ICT policy plan. Consequently, future research may further explore to control infrastructure and ICT policy plan related variables (see our revised model, Figure 2). In addition, we reported in chapter 2 on our model testing results, indicating that Flemish teachers take both the usefulness and the ease of use of the LMS into consideration. In chapter 5, during the interviews, our respondents were positive about the material provided and considered them as ease to use. However, they agreed less about the usefulness. More specifically, they doubt whether learning paths are adequate to attain better learning outcomes. In Chapter 5, much consideration was given to external (first-order) and internal (second-order) 'barriers' hindering technology integration (Ertmer, 1999). Two approaches, teacher-centered and student-centered beliefs about instruction (Kember, 1997), offer a plausible explanation on why teacher adopt or do not adopt a specific instructional method/technology. In this respect, we can argue that not being convinced about the usefulness was possibly strengthened by teachers holding teacher-centered belief (Sang, Valcke, van Braak & Tondeur, 2010). Thus, it could have been interesting if we had developed teacher 'profiles', building on the extent they adhere a level of teacher-centered beliefs and student-centered beliefs. Future research should therefore take into account the complex tension between external and internal barriers, as we partly did in the present research.

When looking at the level of experience with LMS tools in Flemish secondary education, we pointed to earlier research indicating that the 'learning path functionality' (10% of all teachers) is hardly observed (De Smet & Schellens, 2009). Based on the available TAM literature, we expected the level of experience would influence the informational use of an LMS. This was confirmed in our TAM model (see Figure 2, Chapter 2). In addition, in Chapter 5, we did not reveal a relation with experience and communicational use, as no teacher had ever used a learning path before. In this regard, arguments that were mentioned why some teachers were more reluctant to use new challenging tools are 'not feeling confident to use ICT', 'the lack of professional development', 'loss of control' and the feeling 'pre-service training did not pay enough attention to ICT classroom use'. On the basis of these empirical findings that emerged, we can conclude that both pre-service training and professional development will have to make substantial efforts if we want to motivate teachers to integrate ICT and LMS within their

teaching. As a result, we added the 'teacher professional development' variable to our extended model (Figure 2), which includes extensive courses, resources and activities that are aimed to help teachers possess all the required knowledge, skills and attitudes to use new challenging tools such as learning paths.

As mentioned above, we tried to consult the students directly in this dissertation, but we were not able to gather sufficient data. As a consequence, we took student participation indirectly into consideration. In Chapter 5, teachers mentioned for example that students adapt quickly to studying with learning paths, on the other hand they got bored within the learning path approach after about three lessons. This is not surprising, as it is a considered a good practice in teacher education to vary the instructional method applied regularly (Keller, 1987). This introduces the need to balance computer use with face-to-face teaching/learning activities.

In Chapter 3, we noticed that students in the individual setting, outperform their peers in the collaborative setting. In Chapter 4, this is also the case for girls in the individual setting, but not for boys, as they perform better in mixed groups. Unfortunately, it not appropriate to compare both studies, since group composition was not part of the design of the study described in Chapter 3. Secondly, we faced unbalanced sample conditions in Chapter 3 that hamper comparison with the results reported in chapter 4. Thirdly, we did not use the same knowledge tests in Chapter 3 and Chapter 4.

Limitations of the studies and directions for future research

The study sample

All studies took place in secondary education in Flanders (Belgium). In Chapter 2, we selected 505 secondary school teachers in seventy-two schools and stratified for region and educational network. Although context or cultural differences between educational systems should never be ignored (Zhu, Valcke & Schellens, 2008), the study in Chapter 2 can easily be generalized to most secondary school teachers. Generalizing the findings from Chapters 3, 4, and 5 is more difficult. In these chapters, our sample was not designed by applying a stratification framework and students were not randomly assigned to conditions. In Chapters 3 and 4, random assignment of students to conditions was not possible, given the authentic school and classroom setting. In Chapter 3, complete classes were assigned to four conditions (individual MGL learning path, individual TSPW learning path, collaborative MGL learning path, and collaborative TSPW learning path). In Chapter 4, classes were assigned, either to the conventional instruction format or to the learning path format. Within these types of instructional formats, students were randomly assigned to either work alone or collaboratively. When working collaboratively, students were randomly assigned to work in mixed gender or in same-sex groups. Given our research setting in authentic classrooms, random assignment of individuals to particular conditions is considered less feasible, impractical, or sometimes even unethical (Weathington, Cunningham & Pittenger, 2010). Considering the (lack of) stratification framework being used, more classroom research is needed in view of generalization.

The study variables

In this dissertation, we focused on teacher acceptance of LMS (Chapter 2) and teacher perceptions on integrating LMS in their teaching (Chapter 5). Measurement limitations can be mentioned in relation to both these chapters.

As indicated in Chapter 2, we measured the constructs informational use and communicational use, as defined by Hamuy & Galaz (2010), on the base of self-reports. We were able to validate the categorization of LMS-interactions and could clearly identify the constructs mentioned above. However, we acknowledge that using log files to report the teachers' LMS-usage can help to generate more accurate LMS related data about the types of LMS-usage. Unfortunately, this was not feasible in this study, given the number of respondents (505 teachers) and the difficulties in getting access to their log files (72 different schools, using LMS from different vendors). Further research on the technology adoption of LMS in secondary education and/or the instructional use of LMS, should focus on the refining of LMS usage categories and add additional variables which help explain if and how LMS are used by secondary school teachers.

In Chapter 5, we build on teacher perceptions as expressed during interviews. Future research could pay attention to their actual behavior and classroom activities. Our research only involved teachers; students are concerned with this as well, and they should take part in future research. These studies can take into account additional student background variables (such as previous educational history, prior knowledge, motivation, aspirations, and social-economic status), focus on other outcome measures, and consider other student samples.

A few technology-related limitations occurred. The advantage of studying via computer-based instruction was reaffirmed. However, additional research is needed and should further investigate the exact conditions under which students benefit from this type of learning. In this respect, recent research stressed the importance of gaining insight into students' use of the whole toolset instead of focusing on a specific tool (Lust, Vandewaetere, Ceulemans, Elen & Clarebout, 2011).

Regarding the use of learning paths in a collaborative setting (Chapter 3 and Chapter 4), future research should pay more attention on how these projects are structured (Barron, 2003) and how meta-cognition strategies can help group members socially interact in ways that enhance collaboration and elaborate knowledge (Ding, 2009; Fullan, 2010).

The e-capacity framework of Vanderlinde and van Braak (2010) consists of four mediating concentric circles with conditions that support ICT uses in education. We focused on the two inner 'circles': 'ICT-related school conditions' and 'ICT-related teacher conditions', and were able to identify several barriers affecting the successful integration of LMS. Future research could emphasize the potential impact of the other circles, e.g. leadership, decision making formats, or collaboration between teachers; but they could also take into consideration factors in a broader context, such as politics, globalization, etc.

An authentic setting

As stated in our introductory chapter, the present dissertation was set up to contribute to the research-practice nexus. We therefore opted to set up our empirical studies in real classroom settings. Despite the resulting ecological validity (Brown, 1992), this also leads to a less-controlled research setting. For instance in Chapter 3, we asked teachers to refrain from any form of evaluation between the pre-test and the retention test, but due to a monthly evaluation system within the participating schools, teachers could not keep to this condition. As a result, we had to limit our focus to the pre- and post-test differences. Another limitation in this chapter was the unbalanced number of students within particular research conditions. Due to a long-term illness, one teacher cancelled her participation; another teacher was fired. Given the last-minute nature of these 'incidents', we were not able to recruit new teachers or to redistribute teachers and their classes over conditions. In summation: a representative design has its limitations, but given our educational level studied, our sample size, and the use of formal statistics, we were able to address methodological issues that arose in other studies (Kay & Knaack, 2008b).

Implications of this dissertation

Theoretical implications

At the theoretical level, the studies contribute to a better understanding of LMS acceptance by secondary school teachers, the way this group of teachers actually uses an LMS in their instructional setting, how the design and implementation of learning paths influence learning outcomes, and which teacher and school variables affect the adoption and the use of LMS. All studies were conducted at the secondary school level, an understudied level within educational research.

In Chapter 2, we extended the TAM2 model with contextual factors and factors reflecting real world settings in order to further develop the understanding of LMS adoption. In addition, the instructional use of LMS by secondary school teachers was further explored and refined. Moreover, the operationalization of instructional use of an LMS into informational use and communicational use appeared to be valid. The research model was able to explain 36% of the variance in informational use and 26% of the variance in communicational use; informational use was found to be positively associated with communicational use. These findings add to the literature on LMS acceptance, lead to a better understanding of the sequence of adoption levels with respect to LMS use, and provide further insight into the relationship between the variables describing LMS adoption and LMS usage.

In Chapter 3, the superiority of a learning path, optimized with Mayer's (2003) guidelines, was found to be in line with previous research about the critical role of spatial abilities within STEM-education (Super & Bachrach, 1957; Wai et al. 2009; Mayer & Sims, 1994). Learning paths, optimized with Mayer's guidelines, lead to a better elaborated and structured course, and thus,

offer better spatial visualization as compared to learning paths building on text, schemes, pictures, and web-based exercises.

In Chapter 4, our findings showing a superiority of studying individually with a learning path as compared to conventional instruction on retention test scores, were found to be in line with previous research comparing conventional instruction and computer-based instruction by Christmann, Badgett, and Lucking (1997) and Lockee, Moore, and Burton (2004), and with previous research on the 'the testing effect' by Dirkx, Kester, and Kirschner (2014). Our findings emphasize the strong impact of the way learning paths are visually presented, as they help shape the student learning experience and actual learning outcomes (Stubbs, Martin, & Lewis, 2006). The underperformance of the collaborative conditions underlines the necessity for further research into group dynamics and meta-cognition strategies (Ding, 2009; Fullan, 2010) to improve collaborative learning.

In Chapter 5, we conducted a qualitative research, studying of the use of learning paths within an LMS in a real secondary classroom setting. The study identified several barriers at the school and teacher level affecting the successful implementation of learning paths, and thus helped to put the e-capacity model of Vanderlinde and van Braak (2010) into practice. It also provides insight into teacher attitudes and perceptions towards using learning paths as an educational tool, students' learning outcomes, and on learner-characteristics that foster learning in an LMS. Our findings emphasize the importance of a reliable and accessible ICT infrastructure, the need for consistent qualitative technical and pedagogical support, and the need for more teacher professional-development programs.

Practical implications

Based on our conclusions in Chapter 2, school managers or LMS coordinators can consider the following practical recommendations: First, introduction sessions for teachers should be considered and manuals provided. If applicable, a decent translation of LMS to the native language of the teacher should be undertaken. Second, given that some teachers are not familiar with functionalities like the wiki or the learning path module, it is important to explain the functionality of each LMS tool separately. Providing best practices, continuous training, and easy access to pedagogical and technical support will definitely be valuable for teachers, and may help to inspire them.

Chapter 3 and 4 are important for teachers and instructional designers, when they are creating learning materials to be used and implemented in an online learning environment. Firstly, we showed a significant impact of learning paths on learning, as they lead to higher scores compared to conventional instruction. Secondly, we demonstrated the importance of visual representations. Thirdly, we demonstrated that one should be careful when implementing collaborative learning in the context of STEM. We found that females perform better within same-sex groups, while males achieve better results within mixed-groups. Thus, our research suggests that prior experience and knowledge regarding collaborative learning are essential. In

addition, meta-cognition strategies (Ding, 2009; Fullan, 2010) could be applied to improve collaborative learning.

In Chapter 5, the implications for policy makers and school leaders are that they need to prevent the conditions that teachers reframe from integrating ICT or using the LMS when teaching. Focusing on school and teacher conditions, we clearly demonstrated that the e-capacities of the schools under study are underdeveloped. Next, teachers refer to critical missing conditions: a reliable and accessible ICT infrastructure, the availability and quality of technical and pedagogical support, integrated teacher professional development programs, and the mastery of critical teacher ICT competencies. When policy makers and school leaders make these technological conditions available to their teachers, they will benefit from technological changes and opportunities.

Final conclusions

This dissertation started from personal experiences as a pre-service teacher trainer. Both in the teacher education context and in the classrooms visited to support pre-service teachers, it could be noted that LMS-usage was limited and most LMS functionalities were rarely applied.

Our state-of-the-art study on the use of LMS by secondary school teachers confirmed these anecdotal observations. As a result, two intervention studies were set up to introduce and research learning paths within LMS. These studies revealed the importance of visual repressions, the (partial) impact of gender on group composition, and gathered descriptive and explanatory information about teacher difficulties implementing collaborative learning into their teaching practice. Our qualitative research uncovered several school-level and teacher-level barriers that prevent teachers from adopting advanced LMS functionalities in particular, and ICT in general.

The main difficulty of this dissertation was taking into account the complexity of the learning process and its key players within an authentic situation. We are convinced that this dissertation presents an interesting perspective on the complex process of digital learning in an authentic secondary classroom setting, on which further developments and future research can be based.

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Nederlandstalige Samenvatting

Het gebruik van een learning management system in het secundair onderwijs: ontwerp- en implementatiekenmerken van leerpaden.

Context

Dit doctoraat heeft als uitgangspunt de persoonlijke ervaring van de doctorandus als lerarenopleider met het gebruik van ELO's (Elektronische Leeromgeving of ELO, ook learning management system of LMS) binnen de eigen instelling (Hogeschool Gent) en binnen de stagescholen. Gezien de achtergrond van de doctorandus, wil dit proefschrift niet alleen bijdragen tot de theorievorming, maar ook relevant zijn voor de onderwijspraktijk.

Centrale probleemstelling

Het uiteindelijke doel van dit doctoraat is enerzijds onderzoeken hoe leerkrachten secundair onderwijs hun ELO inzetten, en anderzijds het ontwerp en de implementatie van leerpaden bestuderen. Dit doel werd omgezet in 5 onderzoeksdoelen:

1) De technologieacceptatie nagaan bij leerkrachten secundair onderwijs, gebaseerd op het geavanceerde Technologie Acceptatie Model (ook TAM2 genaamd) van Venkatesh en Davis (2000).

2) Het tweede doel is gelinkt aan het eerste. We onderzoeken hoe leerpaden ingezet worden bij instructie, en meer specifiek de relatie tussen 'informational use' en 'communicational use' zoals gedefinieerd door Hamuy en Galaz (2010). We gaan na of er een positief verband bestaat tussen 'informational use' en 'communicational use'.

3) Onderzoeksdoel drie is gericht op het bestuderen van de impact van ontwerp- en implementatiekenmerken op de leerwinst van leerlingen secundair onderwijs die studeren met leerpaden, waarbij geslacht als een moderator beschouwd wordt.

4) Onderzoeksdoel vier betreft een vergelijkende studie tussen leerpadgebaseerde instructie en conventionele instructie, waarbij hetzij individueel hetzij collaboratief gewerkt wordt, en waarbij rekening gehouden wordt met de groepssamenstelling, en geslacht opnieuw als een moderator beschouwd wordt.

5) Onderzoeksdoel vijf gaat de perceptie na die leerkrachten hebben wanneer ze leerpaden gebruiken binnen een ELO, in relatie tot de condities op school-, leerkracht- en leerlingniveau, en onderzoekt hoe dit de acceptatie van leerpaden beïnvloedt.

Theoretische basis

Dit proefschrift is gebaseerd op enkele conceptuele raamwerken. Bij het onderzoeken van de technologieacceptie van de ELO door leerkrachten secundair onderwijs, bouwen we verder op het TAM-model van Davis (1989) en het TAM2-model van Venkatesh en Davis (2000). De leerpadstudies bouwen verder op de Cognitive Load Theory (Baddeley, 1986; Sweller, 1994), de Cognitive Theory of Multimedia Learning (of CTML; Mayer, 2005) en het onderzoek rond samenwerkend leren binnen de Computer Supported Collaborative Learning (of CSCL; Dillenbourg, Baker, Blaye & O'Malley, 1996) gemeenschap. Het volledige doctoraat kan dan weer gelinkt worden aan het e-capacity framework van Vanderlinde en van Braak (2010), aangezien we focussen op twee van de door deze auteurs onderscheiden condities die een impact hebben op de integratie van ICT: schoolgerelateerde en leerkrachtgerelateerd condities.

Studie 1

In hoofdstuk 2 van dit doctoraat werden onderzoeksdoel één en twee uitgewerkt. Hiervoor werd gebruikgemaakt van een vragenlijst die door 505 leerkrachten secundair onderwijs werd ingevuld. Ons theoretisch model op basis van het TAM2-model (met als basis variabelen 'perceived usefulness', 'perceived ease of use' en 'subjective norm') werd uitgebreid met de volgende variabelen: 'personal innovativeness towards IT', 'internal ICT support' en 'experience'. Het door de leerkracht zelfgerapporteerd gebruik van de ELO werd geconceptualiseerd als 'informational use' en 'communicational use'. Na analyse via pad-analyse, kunnen we besluiten dat ons theoretisch model 36% van de variantie in 'informational use' verklaarde en 26% in 'communicational use'. Daarnaast concluderen we dat er een positief verband bestaat tussen 'informational use' en 'communicational use'.

Studie 2

In hoofdstuk 3 onderzochten we de impact van ontwerp- en implementatiekenmerken bij leerpaden binnen een ELO, op de leerwinst van leerlingen secundair onderwijs, rekening houdend met het geslacht van de leerling. Daartoe ontwierpen we 2 verschillende soorten leerpaden, gebaseerd op de Cognitive Load Theory en de Cognitive Theory of Multimedia Learning. Het eerste leerpad bevatte volgende leerobjecten: tekst, schema's, afbeeldingen en online oefeningen, het tweede leerpad werd ontworpen volgens de ontwerpregels van Mayer (2005) en aangevuld met advanced organizers (Ausubel, 1960). Leerlingen studeerden het leerpad hetzij individueel, hetzij via samenwerkend leren. Dit resulteerde in een 2 x 2 design. Alle leerkrachten ontvingen lesvoorbereidingen zodat we de uniformiteit van het onderzoek in zijn geheel konden garanderen. We peilden naar de kennis van de leerlingen op 3 testmomenten: vooraf (pre), aan het einde van de vierde les (post) en één maand na de laatste les (retentie). Via multilevel analyse werden de resultaten geanalyseerd. We vonden dat meisjes en jongens die individueel een met Mayer's ontwerpregels geoptimaliseerd leerpad doornamen, de beste resultaten behaalden. Onze hypothese dat leerlingen die samenwerken beter scoren, en meisjes in het bijzonder, werd niet bevestigd. Onze hypothese dat jongens betere resultaten

zouden halen met een via Mayer's ontwerpregels geoptimaliseerd leerpad, aangezien dit de spatial ability (of ruimtelijke visualisatie) bevordert wat voornamelijk voor jongens belangrijk is, werd bevestigd.

Studie 3

In hoofdstuk 4 vergelijken we leerpadgebaseerde instructie met conventionele instructie, waarbij we rekening houden of er individueel dan wel collaboratief gewerkt wordt, waarbij we de groepssamenstelling bijhouden en het geslacht van de leerling opnieuw opnemen als moderator. Hoofdstuk 4 bouwt verder op Hoofdstuk 3 en behield volgende zaken: het met Mayer's ontwerpregels geoptimaliseerde leerpad (bestaande uit 4 lessen biologie rond bacteriën) en de lesvoorbereidingen voor de leerkrachten die met een leerpad werkten. De kennis van de leerlingen werd opnieuw (met geoptimaliseerde testen) getoetst op 3 testmomenten: vooraf (pre), aan het einde van de vierde les (post) en één maand na de laatste les (retentie). Via multilevel analyse werden de resultaten geanalyseerd. Onze hypothese dat leerlingen in de leerpadgebaseerde instructie beter zouden scoren dan in de conventionele setting werd bevestigd. Het verwachte positieve effect van samenwerkend leren bleef opnieuw uit. We vonden wel een belangrijk resultaat wanneer we het geslacht van de leerling en de groepssamenstelling bekeken. Jongens bleken significant betere resultaten te behalen wanneer ze samenwerkten met een meisje, terwijl meisjes betere resultaten behaalden wanneer ze of alleen konden werken of samen met een ander meisje een groepje vormden.

Studie 4

In hoofdstuk 5 rapporteren we onze kwalitatieve studie, i.e. een analyse van interviews afgenomen tijdens studie 2 en 3 met 16 leerkrachten secundair onderwijs. Deze studie baseert zich op het e-capacity framework van Vanderlinde en van Braak (2010) en op opvattingen m.b.t. e-learning in het onderzoek van Liaw en Huang (2007), Liaw, Huang en Chen (2007) en Liaw (2008). De data werd geanalyseerd via het softwarepakket Nvivo. Het doel van deze studie was de condities achterhalen op school- en leerkrachtniveau die het gebruik van leerpaden beïnvloeden. Op schoolniveau vonden we dat meerdere factoren zoals, 1) de beschikbaarheid en het functioneren van de infrastructuur, 2) het gebrek aan pedagogische support en 3) opleidingen voor de leerkracht, de integratie van ICT verhinderen. Daarnaast onderzochten we ook welke percepties en verwachtingen leerkrachten hebben m.b.t. het werken met leerpaden als educatief materiaal, en hoe dit gerelateerd is aan leerwinst en leerling-karakteristieken. We concluderen dat leerlingen vlotter konden werken met onze leerpaden dan de leerkrachten. De meeste leerkrachten waren tevreden met de inhoud en de ontwerpeigenschappen van onze leerpaden. Zowel bij leerlingen als leerkrachten waren de meningen verdeeld over de leerwinst die met een leerpad bereikt kan worden.

Implicaties

Dit doctoraat heeft zowel theoretische als praktische implicaties. Het draagt bij tot de theorievorming wat betreft de technologieacceptatie van ELO's door leerkrachten secundair onderwijs, en tot de verdere operationalisering van 'ELO-gebruik'. Daarnaast toont het aan dat ontwerpkenmerken een belangrijke rol spelen. Zo illustreerden we dat jongens een voordeel hebben bij een goed uitgewerkte ruimtelijke visualisatie van leermateriaal. We vonden ook aanwijzingen dat leerpad-gebaseerde instructie betere resultaten oplevert op de retentie-testen dan conventionele instructie. Tenslotte identificeerden we condities op leerkracht- en schoolniveau die het gebruik van ICT verhinderden. Praktische conclusies omvatten onder meer het advies om de ELO binnen een school goed te kaderen met behulp van introductiesessies, een goede handleiding enz. We toonden, naast het belang van ontwerpkenmerken, ook aan dat de implementatie van een leerpad zorgvuldig moet gebeuren, aangezien onze leerkrachten nog niet vertrouwd zijn met hoe ze leerlingen het beste kunnen laten samenwerken. Ten slotte wijzen we ook op het belang van de e-capaciteit die een school heeft met het oog op een succesvolle ICT-integratie.

Beperkingen

De voorgestelde studies hebben een paar beperkingen. Ten eerste zijn de studies in hoofdstuk 3, 4 én 5 niet gebaseerd op een representatieve steekproef. Een tweede beperking heeft te maken met het operationaliseren van onze variabelen. Zo werden meerdere variabelen niet in het onderzoek opgenomen, zoals bijvoorbeeld socio-economische status, motivatie, eerder verworven kennis enz. Ten derde hebben we gebruikgemaakt van zelfgerapporteerd ELO-gebruik bij de leerkrachten (en dus geen systeemdata) en hebben we in hoofdstuk 5 enkel leerkrachten geïnterviewd om te peilen naar leerlingkenmerken. Als laatste dienen ook enkele beperkingen m.b.t. ons leerpad in acht genomen te worden. Zo hebben we enkel leerpaden binnen het vak biologie bestudeerd, en werd het instructiemateriaal slechts gebruikt in vier lessen. Meer onderzoek is nodig om tot generaliseerbare inzichten te komen

Conclusies

Het technologie acceptatieonderzoek bevestigde dat leerkrachten secundair onderwijs hun ELO weinig gebruiken, en zich meestal beperken tot de meer administratief gerelateerde activiteiten binnen hun ELO. De twee interventiestudies die daaruit volgden en die zich richtten op het studeren via leerpaden in de ELO, leerden ons dat ontwerpkenmerken belangrijk zijn, dat het geslacht binnen de samenstelling van een groep een rol speelt en dat de implementatie van samenwerkend leren niet vanzelfsprekend is. Ons kwalitatief onderzoek leerde ons dat verschillende factoren op leerkracht- en schoolniveau de integratie van ICT belemmeren.

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