THE UNRAVELING OF TOOL USE: ANSWERING THE UNANSWERED?

Norma A. Juarez Collazo[1]*, Jan Elen[2], Geraldine Clarebout[3]

[1,2]Center for Instruction Psychology and Technology, KU Leuven, 3000, Leuven, Belgium
[3]Onderwijsondersteuning Faculteit Geneeskunde, KU Leuven, 3000, Leuven, Belgium
simplementeshelly@gmail.com

Abstract: This paper summarizes the results of four experiments exploring the use of tools. The first experiment shows that the use of tools is not only problematic in computer-based learning environments (CBLEs) and that the functionality of tools is relevant. The following experiments explored the impact of tools (concept maps, adjunct questions), tool-related characteristics (tool delivery mode: non-/embedded tool), tool advice (non- /explained tool functionality) and learner-related characteristics (prior knowledge, self-efficacy, goal orientation, perceptions, self-regulation) on tool use in a CBLE. Tool use on performance was also studied. The results indicate that all aforementioned characteristics influence tool use; there seems to be an interaction between the tool and the learner, and time spent on the tool seems crucial to determine performance.

INTRODUCTION

From an instructional design perspective, the presence of support devices, also known as tools in computer-based learning environments (CBLEs) aims to enhance learning outcomes/performance [1]. Nevertheless, independent of the intentions behind the design of the tools, tools are value-neutral until learners use them [2]. How (in-) adequately learners use the tools affects the tools functionality and hence influences the performance [3]. However, using tools often seems an unappealing activity for learners and hence they often avoid to use the tools [4].

The problem raised by tool use indicates that there is a complex, interactive and non-linear tool-learner relationship [5]. Unfortunately, this relationship of tools and learners as intellectual partners and their partnering processes is still limited in research and needs to be unraveled. On the one hand, there is the tool with different characteristics. These characteristics are linked to the intention of the instructional designer [6]. On the other hand, there is the learner with inherent, intrinsic characteristics. These characteristics are cognitive, metacognitive as well as motivational. How exactly tool and learner characteristics interact and affect tool use; and how tool use impacts the tools' functionality and therefore influences performance are questions that were examined in the course of four experiments (Table 1).

The four studies were built upon Winne's cognitive conditions, Perkin's framework and Iiyoshi and Hannafin's tool use strategies [5,7,8]. Optimal tool use –which would lead to positive learning outcomes-was conceptualized as a thoughtful process in which:

1. The tool is present and functional. The impact of tool use on performance should reveal the tools functionality. Additionally, if the tools are present, further characteristics associated to the tools may come into play. These are the type of tools (eg. cognitive tools), the tools delivery mode (embedded vs. non-embedded tools) and tool advice (explanation vs. no explanation of tool functionality).

2. Learners recognize the tool [5], choose the tool that may be better for their learning [7], and use the tool(s) skillfully [8]. If learners are capable of recognizing, choosing and using tools skillfully, they possess metacognitive characteristics such as perceptions and self-regulation skills that help them in the tool use process.

3. Learners are motivated to use the tools skillfully. Learners' motivation determines the effort learners will invest in using the tools and is therefore linked to the optimization of tool use. Self-efficacy and goal-orientation are two characteristics with a motivational nature that have been explored in tool use research [5,7-9].

In addition to the aforementioned tool and learner characteristics, these conditions also refer to a learner characteristic with a cognitive nature that should not be taken for granted when investigating tool use. This characteristic, namely domain-specific prior knowledge is inherent to the learner. Prior knowledge is known for its power to predict performance [9,10] and is considered as an important characteristic either enabling or impeding learning with the use of tools [8,11,12]. Prior knowledge also seems to impact tool use and interact with metacognitive and motivational learner characteristics [11-13].

THE STUDIES AND SUMMARY OF FINDINGS

The initial study was exploratory and was essential to set the baseline of the following studies. In order to do so, it was important to first investigate whether the complexity of tool use only stood by CBLEs or not. Therefore, we endeavored to analyze the use of tools in an environment extrinsic to CBLEs. The use of tools was examined in a learning environment using a psychomotor task [14]. Learners had to build a LEGO figure with the help of two tools: a guideline and/or a video. There were four conditions, with guideline, with video with guideline and video and with no tools. The results revealed that the tools were functional: Significant positive effects on performance were observed. This means that the groups using tools performed better than those without them. However, when confronted with multiple tools, learners had trouble identifying the most functional tool. It seems that the different types of tools

influenced the way learners perceived the tool functionality. As a consequence, learners used the "least functional tool" instead. Effects of learner characteristics and further tool characteristics could not be retrieved.

In the subsequent studies (1, 2 and 3) more extended and in-depth investigations were performed. The experimental studies were carried out in a CBLE context. The experiments only differed with respect to the tools used: Adjunct questions (Study 1), semi-structured concept maps (Study 2) and multiple tools: adjunct questions and semi-structured concept maps (Study 3) [15,16]. Each of the studies had two embedded conditions with explanation of the tool functionality and two non-embedded conditions without explanation of the tool functionality. Studies 2 and 3 included a control condition (no tools, no explanations of the tool functionality). In general the results revealed that domain prior knowledge, embedded tools and adjunct questions influenced quantity of tool use positively. In contrast, goal orientation, self-efficacy and the explanation of the tool functionality showed a negative effect on quantity of tool use while perceptions and self-regulation showed mixed effects. Regarding quality of tool use, goal orientation and non-embedded tools showed a positive relationship with it. Lastly, significant correlations among quantity and quality of tool use were observed and only quantity of tool use impacted performance.

The following section discusses the results in more detail. The findings that are related to the tool functionality and hence the effects of tool use on performance are firstly addressed. Next, the results based on the effects of tool and learner characteristics on tool use are outlined.

MAIN FINDINGS

Tool Use and Performance

In order to fully address the functionality of the tools, it was expected that tool use would impact performance positively [4]. In all the studies, the use of the tools had a positive effect on the performance. In the Exploratory Study, the conditions with tools outperformed the control condition. However, learners using the tool that was considered the 'least' functional showed better performance. Moreover, learners with multiple tools could not see which tool was the most functional one.

In the following studies (Studies 1, 2 & 3) tool use was investigated from a quantitative (time and frequency) and qualitative perspective. Studies 1 and 2 used single tools. Study 3 used multiple tools. In Study 1 (with adjunct questions as tools) the results showed that only time spent on the tools impacted performance in a positive way. The other aspects of tool use (frequency and quality) showed no significant effects on performance. In Study 2 (with semi-structured concept maps as tools), both aspects of quantity of tool use (time and frequency) influenced performance. The results were mixed. While the time spent on tools impacted performance positively, frequency of tool use had a negative impact on performance. Quality of tool use did not impact performance significantly. To allow further comparisons and possibly analyze the tools functionality more deeply, Study 2 included a control condition without tools. The addition of a control condition revealed that

the differences among conditions in relation to performance were minimal and no significant differences could be retrieved. This means that the learners in the conditions with tools did not perform any better than the ones with no tools, but they did not perform worse either.

In the last study (Study 3: with adjunct questions and semi-structured concept maps as tools), positive effects of time spent on the tool on performance were observed. However, these effects were only observed when using the adjunct questions. Time spent on the semi-structured concept maps did not significantly impact performance. Furthermore, neither frequency nor quality of tool use of either of the tools impacted performance in a significant way. However, a significant difference regarding performance was retrieved between learners using tools and those with no tools (experimental vs. control condition).

Interrelationships among time, frequency and quality were also investigated in Studies 1, 2 and 3. The results, first, indicated that there seemed to be significant correlations between frequency and quality of tool use. The direction of this relationship, however, is mixed. Study 1 suggested a negative correlation between quality and frequency of tool use while Study 2 indicated a positive relationship among these two tool use measurements. Study 1 used adjunct questions and Study 2 employed semi-structured concept maps. In addition, in Study 3 a negative correlation between quality of tool use and time spent on tools (in adjunct questions) was reported; also a positive relationship between time spent on adjunct questions and time spent on concept maps was found. Figure 1 represents the aforementioned findings.

Learner and Tool Characteristics Effects on Tool Use

The findings showing the effects of the different learner and tool characteristics will be described in terms of tool use. This means that the different learner and tool characteristics influencing the quantity of tool use (time and frequency) will be firstly explained. The different learner and tool characteristics influencing the quality of tool use will be described afterwards.

Quantity of tool use: Time spent on tools

Self-regulation, perceptions and goal orientation influenced the time spent on the tools. With respect to the tool characteristics,
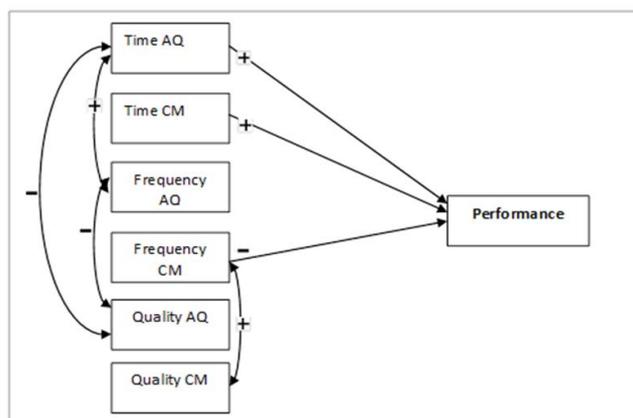

Figure 1: Significant effects of tool use on performance and correlations among time, frequency and quality of tool use. The lines with a + sign indicate a positive relationship. The lines with a – sign indicate a negative relationship.

tool type, tool advice and tool delivery mode influenced the time spent on the tools. How exactly they affected tool use reveals a complex interplay among the different learner and tool characteristics and is further explained.

Three self-regulation skills influenced the time spent on the tools. Two out of these three self-regulations skills, namely 'elaboration' (Study 2) and 'critical thinking' (Study 3) had a positive impact on the time spent on the tools. In contrast, the self-regulation skill of 'organization' (Study 2) impacted time spent on the tools negatively. Considering the definitions of 'elaboration' and 'critical thinking', these results suggest that the more learners were oriented towards a deeper understanding by means of study activities, in this case the use of tools (elaboration), and the deeper the understanding learners had about the tools the more time they decided to spend on the use of the tools [17]. The difference was that high elaborators spent more time on semi-structured concept maps whereas high critical thinkers spent more time on the adjunct questions. Moreover, learners with high organization skills, that is, learners who are able to reorganize learning material to perform optimally were inclined to spend significantly less time on the tools, specifically semi-structured concept maps [17].

The role of perceptions seemed mixed. 'Perceived functionality' showed a negative influence on the time spent on tools. This means that the degree to which learners believed that using a certain tool would enhance his/her performance in order to reach a goal contributed to spending less time on the tools, specifically semi-structured concept maps (Study 2) [18,19]. The effect of perceived functionality, however, was not consistent. This effect disappeared when it was controlled for different conditions (Study 2) and when more learner characteristics were included in the analysis (Study 2). The other perception of tool use, namely 'perceived usability' showed positive as well as negative effects on the time spent on tools. Considering that perceived usability is the degree to which a learner believes that a certain tool would be usable and easy to use, then believing that the semi-structured concept maps would be usable and easy to use led to more time spent on the tools (Studies 2), but believing the same about adjunct questions led to less time spent on tools (Studies 3) [18,19].

High performance avoidance goal orientation had a negative impact on the time spent on tools. Performance avoidance focuses on avoiding normative competence, refers to low competence expectancies, fear of failure and avoidance of failure, which means that learners avoided and feared failure decreased the time they spent on the semi-structured concept maps (Study 3). Figure 2 summarizes the findings on the learner characteristics influencing the time spent on tools [20].

With respect to tool characteristics and their influence on time spent on tools, results were as follows. In general the type of tool influenced the time spent on the tools in Study 1 (adjunct questions) and Study 2 (semi-structured concept map). When multiple tools were used, however, (Study 3: adjunct questions and semi-structured concept maps), spending more time on adjunct questions contributed to better performance than spending time on concept maps. The tool delivery mode (embedded or non-embedded tools) and the tool advice (the

explanation of the tool functionality or no explanation of tool functionality) were characteristics dichotomous in nature in Studies 1, 2 and 3. The results pointed out that learners spent more time on embedded tools (Study 1 and 3) than on non-embedded tools; moreover, it also seemed that learners without the explanation of the tool functionality invested more time on the tools (Study 2) than those with the explanation of the tool functionality. Figure 3 represents these results.

Quantity of tool use: Frequency of tool access:

The frequency of tool use was only examined in non-embedded conditions. Along the studies in this dissertation, no direct effects of tool characteristics on frequency of tool use were observed. Regarding learner characteristics domain prior knowledge (Study 2) and self-efficacy (Study 1) seemed to influence significantly the frequency of tool use. Domain prior knowledge refers to the knowledge learners possess about the topic presented in the instructional text from the CBLE task. As previously addressed, domain-related prior knowledge is an important cognitive learner characteristic to predict learning [9,10] and either enables or impedes learning with the use of tools [8,10,12]. Self-efficacy refers to the personal beliefs about having the means to organize or execute the courses of action to perform effectively (Bandura, 1997), which implies that self-efficacy influences how learners approach tools. The impact of
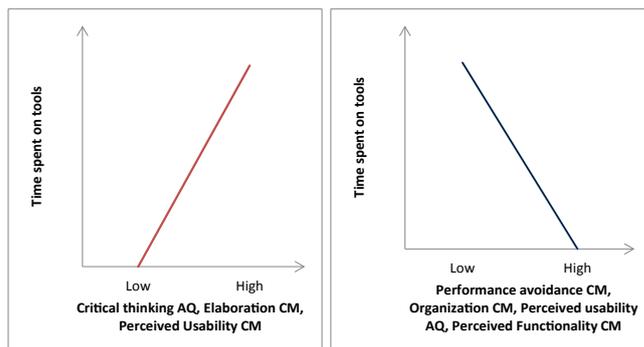

Figure 2: Representation of the results of learner characteristics influencing time spent on tools; CM= Concept Maps AQ=Adjunct Questions. On the left are learner characteristics with a positive relationship on time spent on tools, on the right are the learner characteristics with a negative relationship on time spent on tools.
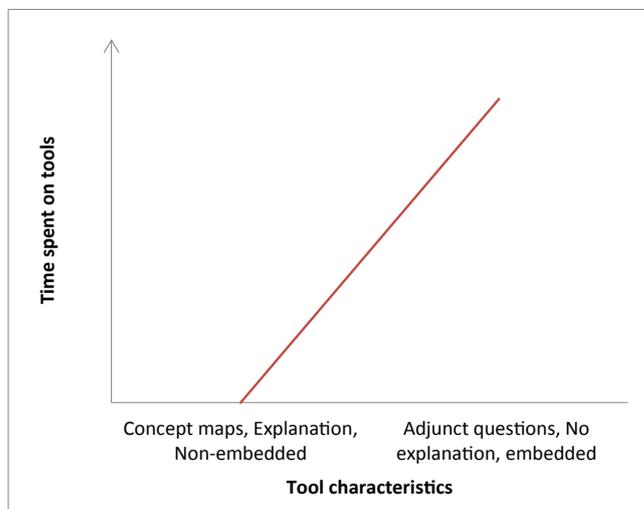

Figure 3: Representation of the results of tool characteristics influencing the time spent on tools.

each of these characteristics is remarkable. Learners with high domain prior knowledge showed more frequency of tool use than with low prior knowledge; whereas learners with high self-efficacy showed less frequency of tool use than learners with low self-efficacy. In other words, learners who knew more about the topic clicked more often on the button that would access the tool, in this case, semi-structured concept maps. On the other hand, the more learners believed in their own ability to complete the CBLE task, the fewer times they attempted to click on the button to access the tool, in this case adjunct questions. Figure 4 summarizes these findings.

Quality of tool use:

Goal orientation and tool delivery mode appeared to have an impact on quality of tool use. The specific goal orientation that influenced quality of tool use was performance approach (Study 1). Performance approach is related to learners' concerns about how well they perform and how others perceive their behavior [20]. This means that learners who were more concerned about their performance and how others perceived it had more thorough answers in the adjunct questions than learners who were less concerned about public recognition. Additionally, low and high mastery avoidance also impacted quality of tool use positively but only in interaction with the non-embedded conditions. This suggests that learners striving to avoid misunderstanding, failing, making mistakes and/or doing anything wrong along with the freedom to access the tools affected the way learners answered the adjunct questions [20]. Finally, the non-embedded conditions also impacted quality of tool use directly (Study 1). Learners with the freedom to access the tools showed better responses in the adjunct questions. These findings are summarized in Figure 5.

All in all, these results allowed sketching the complexity of tool use not only in a CBLE but also in a psychomotor context (Exploratory Study). The findings also make several noteworthy contributions to the phenomenon of tool use regarding the effects of tool and learner characteristics on tool use, and the impact of tool use on performance. However, the present findings do not give a uniform answer to the tool use problem. They rather present an intricate picture of the relationships between learner characteristics, tool characteristics, tool use and performance

and question the functionality of the tools. In addition, these results raise further questions. These questions are comprised in three issues regarding the impact of 1) tool use on performance which relate to the tool functionality 2) learner characteristics on tool use and 3) tool characteristics on tool use. Furthermore, methodological issues are addressed. These issues constitute a challenging research plan that is further discussed (Figure 6).

Discussion

Issue 1: Tool Use and Performance:

With regard to the lack of coherence in the effects of tool use on performance, two main research questions can be identified. A first question deals with whether the tool measurements (time, frequency and quality) are valid indicators of what they claim to evaluate. For instance, given the positive correlations, it is wondered whether frequency of tool use can be more a measure of quality than of quantity of tool use or whether quality of tool use can be more a measure of quantity of tool use. Literature has already suggested that quality can be examined using time variables [21]. It is also wondered whether frequency and quality of tool use are indicators of the same underlying variable. The correlation found in this dissertation suggests that the high frequency of tool use is closely related to the quality of tool use and together affect performance negatively. Given that
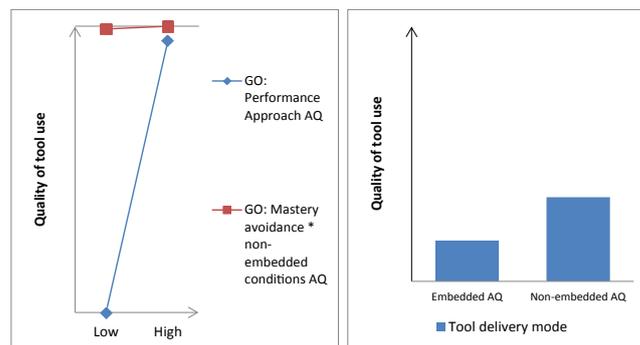

Figure 5: Representation of the results of learner characteristics influencing quality of tool use (left); Tools characteristics influencing quality of tool use (right). GO= goal orientation AQ=Adjunct Questions.
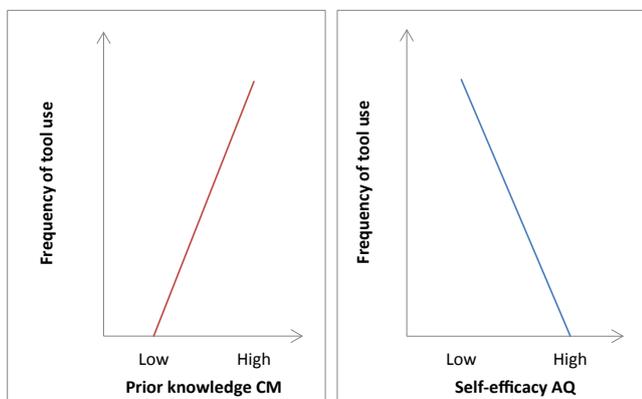

Figure 4: Representation of the results of learner characteristics influencing frequency of tool use. CM= Concept Maps AQ=Adjunct Questions. On the left is prior knowledge with a positive relationship on frequency of tool use, on the right is self-efficacy with a negative relationship on frequency of tool use.
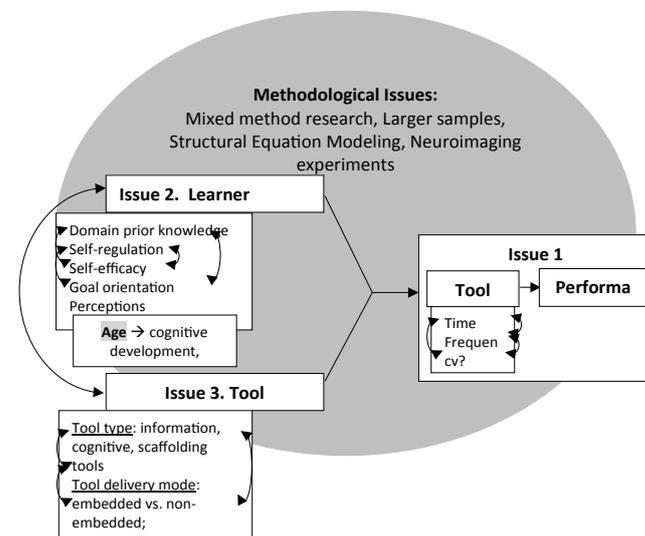

Figure 6: Future research model.

frequency of tool use was only measured in the non-embedded conditions, then it could be possible that non-embedded tools may indirectly hamper performance, as well. This positive correlation between frequency and quality of tool use could only be observed when learners used semi-structured concept maps as the tools. When learners used the adjunct questions, frequency of tool use affected performance negatively. This finding suggests that the type of tool may influence tool usage behavior. Therefore the correlations among time, frequency and quality of tool use should be further explored along with different tool types and tool delivery mode (Figure 6).

A second question relates to how these results challenge the functionality of the tools by raising the question on (a) whether the three tool use measurements (time, frequency and quality) are necessary elements to explain tool usage, and on (b) whether the three tool use measurements should impact performance in order for the tool to be considered as functional. Studies on tool use seldom explored time, frequency and quality in a single study. For instance, Crippen and colleagues explored frequency and retrieved a positive impact on performance [22]. Elen and Louw saw only partial effect of frequency of tool use on performance, while Viau and Larivée showed effects of both time and frequency on performance [1,23]. Few studies have simultaneously explored the time, frequency and quality of tool use [24,25]. Clarebout and colleagues only found significant positive effects of time and quality on tool use on performance; Jiang and Elen had positive effects of quality of tool use on performance but negative effects of frequency of tool use on performance and partial effects of time on tool on performance [24,25]. Other studies have not analyzed the effects of tool use on performance [26,27]. This evidence may therefore indicate that in a single study three tool use measurements may not be necessary in research on tool use. It could be that time, frequency and quality of tool use either compensate for each other or because they measure essentially the same. However, it is also wondered under what circumstances, how and what interrelationships between tool and learner characteristics impact tool use (time & frequency) which in turn influences performance (Figure 6).

Issue 2: Learner Characteristics on Tool Use:

The second issue relates to the identification of learner characteristics that strongly affect tool use. This dissertation was based on the theoretical assumption that prior knowledge, metacognitive and motivational characteristics are relevant in CBLEs. The results of the studies indicated that indeed all these characteristics may be important to consider regarding tool use.

Domain prior knowledge was considered an important cognitive variable with the power to restrain or encourage tool use [8]. Prior knowledge showed a positive effect on the frequency of tool use (Study 2). This finding contradicts the results from Renkl's study (learners with high prior knowledge accessed tools less often), and at the same time, it reveals that prior knowledge may interact with the tool delivery mode (embedded vs. non-embedded) [11]. Learners with high prior knowledge were more inclined to access the tools in the non-embedded conditions than those with low prior knowledge. However, given that frequency of tool use impacted performance negatively (Study 2), high

levels of prior knowledge may have indeed tainted tool use, hence performance. These results are somewhat puzzling since they bring to light that there may be an interaction between prior knowledge and the tool delivery mode (Figure 6: Issue 2). A further discussion is provided in issue 3.

Metacognitive characteristics are essential for learners to determine to what extent tools can aid their learning [4,7]. The results with respect to the impact of the metacognitive characteristics were striking but not always consistent. For instance, both perceptions and self-regulation skills impacted the time spent on the tools in both a positive and a negative way. In relation to self-regulation skills, 'critical thinking' encouraged more time spent on the adjunct questions (Study 3) while 'elaboration' encouraged more time on the semi-structured concept maps (Study 2). In contrast, 'organization' contributed to spending less time on the semi-structured concept maps (Study 2). Regarding perceptions, 'perceived functionality' of concept maps had a negative effect on the time spent on the tools (Study 2). Additionally 'perceived usability' of concept maps showed a positive effect on the time spent on tools (Study 2) but 'perceived usability' of adjunct questions showed a negative effect on the time spent on tools (Study 3). Moreover, given that time spent on tool impacted performance, these results also suggest that self-regulation and perceptions indirectly affect performance. These results strongly suggest self-regulation skills and perceptions interacted with the tool type. How exactly and what levels of self-regulation skills and perceptions affect tool use and how they relate to tool type should be further analyzed. Adding more diverse tool types into future experiments could allow further comparisons (Figure 6: Issue 2 & 3). Moreover, although the log files provided a rich dataset, a deeper insight is needed. Observation techniques could provide additional data on the learners' behavior that cannot be retrieved through log files only. (Figure 6: Methodological issues).

Motivational characteristics are crucial to prompt tool use [4,7]. The findings regarding the motivational characteristics show that the effects of goal orientation and self-efficacy are not always linear. For instance, low and high levels of mastery avoidance in interaction with non-embedded conditions had a positive effect on quality of tool use. In contrast, medium levels of mastery avoidance in interaction with non-embedded conditions did not impact tool use significantly (Study 1). The effects found of the performance orientations indicated that 'performance approach' influenced quality of tool use positively (Study 1) and 'performance avoidance' influenced the time spent on the tools negatively (Study 3). Considering that the more time spent on the tools, the better the performance, then performance avoidance also impacted learning outcomes in a negative way. Furthermore, in the last study (Study 3), size effects of mastery approach on frequency of tool use in concept maps and mastery avoidance on quality of tool use of adjunct questions were retrieved. The results were not significant; however, they do provide evidence of the strength of goal orientation on tool use and supports the claim suggesting that goal-orientation is a promising factor in the complexity of tool use that should be further investigated [28] (Figure 6: Issue 2). In relation to self-efficacy, high self-efficacy levels influenced negatively the

frequency of tool use. The direction of this influence, however, remains unclear.

The results on the motivational characteristics (self-efficacy and goal orientation) put at stake the theoretical position suggesting that motivation is crucial for tool use and therefore encourage to explore tool use more deeply [4]. Based on the present results, it is possible that learners with high self-efficacy also had low levels of prior knowledge and learners with low self-efficacy had high prior knowledge. The interaction among these characteristics may eventually influence the frequency of tool use. However, while our finding gives light to a possible interaction, it was unfeasible to check this implication as the results were obtained in different studies; hence, it is still a conjecture that needs further assessment (Figure 6: Issue 2).

An additional remark in the light of these findings is in line with a possible interaction among learner and tool characteristics. Certain characteristics only affected the time spent on the tools in the presence of certain tools. The self-regulation skills of elaboration and organization, performance avoidance goal orientation and perceived functionality affected the time spent on tools when using concept maps. Critical thinking affected the time spent on tools when using adjunct questions. Perceived usability showed a positive influence when using concept maps but a negative one with adjunct questions. Moreover, mastery avoidance only affected quality tool use in interaction with the tool delivery mode specifically non-embedded conditions. Questions are raised in identifying how exactly the type of tools affect perceptions, and on what kind of learners need embedded or non-embedded tools (tool delivery mode). These findings also challenge the theoretical model in the present dissertation and provoke a hypothesis that tool and learner characteristics may not only interact with each other but also correlate significantly (Figure 6: Issue 2 & 3).

This finding suggests that perceived usability and perceived functionality are valid measures related to tool use in CBLEs. Therefore future studies exploring perceptions of tool use could use the present results as a baseline (Figure 6: Issue 2). How exactly the explanation of the tools affected perceptions seems unclear. Additionally, investigating the relationships between tool and learner characteristics using other research methodology (mixed methods research) or other types of instruments, such as interviews or think aloud protocols could give a deeper insight into these intertwined relationships. This will be further addressed in the methodological issues (Figure 6: Methodological issues).

As a last remark and to increase the complexity of the study of tool use, there may be another reason that contributed to the present findings. Results could be attributed to the learners' age. The cognitive development of learners is modified/improved as they grew older. Consequently, tool use improves with age [28].The older someone is the more developed their cognition is; hence the better the performance in relationship to prior knowledge [28]. Age can be interpreted as a variable that integrates other factors, among those are the educational level and self-regulation skills (Study 2).

Issue 3: Tool Characteristics on Tool Use:

A third issue is related to tool characteristics. This dissertation was based on the theoretical assumption that tool type, tool delivery mode and tool advice has an impact in CBLEs. The results of the studies revealed very interesting findings.

The effects of a functional and a less functional tool were investigated in the Exploratory Study. In the following studies (1-3), two types of cognitive tools were explored. These were a knowledge organization tool (semi-structured concept map) and a knowledge generation tool (adjunct question). The findings in all studies indicate that all the tools were functional, that is, the effects on performance seemed favorable. The positive effects of the different tools were more evident when only one of the two tools was present in the CBLE (Studies 1and 2). However, when learners faced both tools –multiple tools- (Exploratory Study and Study 3), tool use was not as optimal as expected. That means that in the Exploratory Study, the use of the non-functional tool led to better learning outcomes/performance than by using the functional tool; and in Study 3, only the use of adjunct questions, showed a positive relationship with performance.

Specifically, the result of the Exploratory Study was explained in terms of the mirror neuron system: the non-functional tool (video) was more functional given that dynamic visualization may be most efficient in psychomotor tasks; in Study 3 it was discussed that the choice of tools seems to be influenced by how easy to use and usable learners perceive the tool (perceived usability) [29]. This perception may or may not be positive. In general, it could be argued that the results from the Exploratory Study and Study 3 are in line with the task-switching paradigm [30,31]. The task-switching paradigm involves the ability to shift attention between cognitive tasks. This shift (in this case the shift between one tool and the other) make learners more likely to respond substantially slower and with a tendency to make more errors which is addressed as a 'switch cost' [32]. In the Exploratory Study and Study 3 the multiple tools possibly had a switch cost effect in the learners. Switch costs could be investigated in further tool use research by comparing how long it takes for learners to use different tools, the researchers could measure the cost in time for switching from one tool to the other. Researchers could also assess how different aspects of the tools, such as tool familiarity, affect any extra time cost of switching [33] (Figure 6: Issue 3). Another approach could be through neuroimaging experiments which involve the use of different techniques to either directly or indirectly image the function of the brain [32] (Figure 6: Methodological issues).

Another reason why in Study 3 learners were more inclined to use either one of the tools could be caused by the reading skills that were elicited by each tool. Adjunct questions may require more skimming skills, while the concept maps may require more scanning skills. Broadly speaking, skimming is fast reading to get the main idea of the text –thus answer the adjunct question-; scanning is used to locate single fact/concepts – that were necessary to complete the concept maps. Another reasoning could be related to the tool familiarity (Figure 6: Issue 3). It is possible that learners tended to use the tools they are more familiar with (Exploratory Study and Study 3). It is

a challenge in research to discover which tools may be more functional to certain learners, for what tasks and why. Taking qualitative research techniques, such as interviews, into account may provide a better understanding. This is because qualitative research aims to explore the human elements of a topic by locating the researcher into the world and allowing him/her an in-depth understanding on how individuals see and experience the world [34]. In this case, qualitative research techniques may provide a more thorough understanding on how the learners experience the use of tools in CBLEs.

Additionally, the types of tools explored in Studies 1-3 were considered cognitive tools. Among cognitive tools, various subcategories were established [8]. In this study, differences among two different cognitive tools were encountered: a knowledge organization tool (semi-structured concept map) and a knowledge generation tool (adjunct question). The questions are (a) whether a more varied types of tools, for example, information or scaffolding tools can bring different effects on tool use and (b) how other tools (e.g., scaffolding tools) interact with other tool characteristics [35] (Figure 6: Issue 3).

Tool delivery mode, that is embedded and non-embedded tools, was investigated in the present dissertation. Learners using the embedded tools spent more time on the tool, while learners using the non-embedded tools, used tools more qualitatively. More specifically, the learners using the embedded tools with the explanation of tool functionality spent more time on the tools, than those with embedded tools but without explanation. Given that only the time spent on the tools had a positive effect on performance, these results suggest that embedding tools may be a straightforward solution for using tools and ensure positive learning outcomes/performance and enhance tool functionality. However, learners' control over their learning is reduced and this lack of control can taint the individual learning processes [36]. Learners using the non-embedded tools, regardless of the (no) presence of the explanation, used tools more qualitatively. Moreover, learner characteristics of prior knowledge and self-efficacy seem to interact with non-embedded conditions. Thus, it is possible that the role of learner characteristics has more incidence in the non-embedded conditions because there is more room for their influence (Figure 6: Issue 3). In the non-embedded conditions learners have to rely more on their own decisions because they have more 'freedom' to use the tools when they believe they need to. These results are not conclusive, though. In Study 3, the effect of tool delivery mode seemed to be overpowered by the explanation of the tool functionality. The explanation of tool functionality -rather than encouraging the learners to use the tools- discouraged them. Learners with the explanation of tool functionality spent less time on the tools (which eventually affected performance negatively). How and how often the explanation of the tool functionality is added in the CBLE seems a challenge in research on tool use. Learner characteristics may also interact with the explanation of the tool functionality. What and how learner characteristics affect the explanation of tool functionality or vice versa seems a challenge for future studies. Knowing the type of learners a priori may help the designers of CBLEs decide when to embed tools, what kind of tool(s) should be present (information, cognitive and/or scaffolding) and whether or not the explanation of tool use

should be present. It is therefore necessary to conduct more investigations that can help identify the most optimal tool characteristics for every type of learner (Figure 6: Issue 3).

Finally, it is also questioned whether the tool characteristics were well-developed. Regarding tool delivery mode, for instance, in the present studies, the tools were either embedded or non-embedded. The non-embedded tools could be at a zero level of "embeddedness" whereas the embedded tools may vary in their "embeddedness" level [23,37,38]. Considering for instance that if a workout example is provided in such way that learners have to read it then the embeddedness is level 1. If the workout example requires students to calculate and fill in the missed information during problem solving before proceed, then the embeddedness is level 2. If a workout example not only asks for the calculation but also requires students to explain their reasoning, then the embeddedness level is even higher. In this dissertation, it is possible that the embeddedness of the tools varied. When learners used the adjunct questions, they were required to give an answer and provide a reason to it. When learners used the semi-structured concept maps they were required to fill in the blanks with the correct concepts but no further rationale was required. It is therefore possible that different levels of "embeddedness" took place in the tools of this investigation. Having different levels of "embeddedness" for the same tool may allow a deeper insight into the tool delivery mode and its effects on tool use (Figure 6).

Methodological Issues

The findings of the present dissertation raise methodological issues as well. A first methodological issue pertains to the approach of the investigation. The approach was mainly quantitative. Adding qualitative approaches could shed light to many questions that still are unanswered. Most importantly, investigating the use of tools should take a step beyond by adopting different research approaches. A mixed methods research, which has been gaining in popularity since the 1980s, is an approach to research that combines the collection and analysis of quantitative and qualitative data [39]. A mixed methods research is used to tackle a research question from any relevant angle and possibly more than one type of research perspective [40]. For instance, the use of log files in combination with observations, think aloud protocols and/or self-reports (e.g., interviews and questionnaires) could already allow the recollection of data we may not know of; and hence contribute to a more thorough understanding of the tool use problem.

Another methodological issue is related to the design and data analyses. Considering the number of variables involved in the tool use interplay, a larger sample could allow more sophisticated analyses such as structural equation modeling (SEM). More sophisticated statistical analyses in conjunction with qualitative methods can reveal important findings that may lead to the unraveling of tool usage (Figure 6). Additionally, in all the studies the samples comprised only students of educational sciences. This may add limitations to the generalization of the findings. Including more heterogeneous samples could validate the results on the effects of the different learner and tool characteristics of tool use of the present dissertation.

A third methodological issue is raised in response to the research

setting. The studies were run in an experimental setting. The findings could be prone to criticism as they may not reflect real life. It is therefore important to conduct complementary studies in different research settings (i.e., ecological setting). The research setting is also related to the physical, cultural and social environments by which the research study is surrounded [41]. Therefore the different research settings could allow a more generalizable interpretation of the results (Figure 6).

A last methodological issue is related to the presence of multiple tools in a CBLE. Multiple tools may lead to a switch cost in learners. Aforementioned neuroimaging experiments were suggested in order to explore this phenomenon by analyzing the function of the brain. Neuroimaging experiments could provide a more fine-grained insight on the effects of multiple tools on tool use (Figure 6). However, neuroimaging is a relatively new approach to research specially exploring the use of tools in CBLEs. It is therefore a great challenge for future tool use research.

Concluding remarks

In view of the results in this dissertation, a summary is presented as follows. This summary along with the discussion from Figure 6 provides a solid and ambitious research agenda on the optimization of tool use and can be viewed as a guideline for designers and researchers of CBLEs.

- The use of tools is not only a problem pertaining to CBLEs.

- The type of tools interacts with metacognitive characteristics, such as perceptions and self-regulation skills. Specifically, adjunct questions may require higher critical thinking in learners and low perceived usability. On the other hand, concept maps may require learners with high perceived usability, high elaboration and low performance avoidance, low perceived functionality and low organization skills.

- Embedded tools may be the answer to guarantee tool use.

- The explanation of the tool functionality did not influence tool use nor influenced tool use negatively.

- Metacognitive characteristics such as self-regulation skills of critical thinking, elaboration and perceived usability may be crucial to augment the time spent on the tools. These characteristics should be carefully considered as they seem to function in line with the types of tools. Some learner characteristics may have a deeper impact on tool use with certain types of tools than others.

- Motivational characteristics such as self-efficacy and goal-orientation seem to be closely related and intervene on tool use. Self-efficacy may affect tool use by influencing perceived usability. Performance avoidance levels in learners may be closely looked at –at least in research- as it may hamper tool use.

- Metacognitive and motivational characteristics seem to be interrelated on the complexity of tool use.

- Quality and frequency of tool use may not be adequate measurements for tool use: Quality of tool use had an insignificant effect on tool use and frequency of tool use affected performance negatively.

- Spending enough time on the tools may in the end the right answer to optimize tool use by the learner and guarantee the tools functionality.

Additionally, these results provide important insights into two theoretical research frameworks. First, these findings sustain the research paradigm of aptitude-treatment interaction (ATI) [42,43]. The ATI pictures complex relations between the learner and the tools for which little empirical verification is found [44]. The ATI theory points out that instructional strategies or treatments, namely tools, interact with aptitudes which are defined as any measurable characteristic of the learner, in this case learner-related characteristics [45].

Second, these findings sustain the Carroll model [46,47]. In Carroll's Model, performance is a function of the ratio of the time actually spent on learning to the time needed to learn which has been put by McIlrath & Huitt in a simple equation [47,48]. This equation is illustrated below; 'f' corresponds to degree of learning:

$$\text{Learning} = f\,(\text{time spent}/\text{time needed})$$

Time spent is the result of the time available to learn (opportunity) and the time a learner is willing to spent (perseverance) [48]. Time needed is dependent on the time needed to learn (aptitude), and achievement which is the ability to understand the instruction and the quality of instruction [48]. Considering this model, positive effects of tool use on performance, may therefore merely depend on the amount of time learners spent on the tools. However, time should not be viewed in a simplistic, sheer manner. Carroll himself has indicated that "time as such is not what counts, but what happens during that time" [47]. Hence optimizing the learning time is an important factor to improve performance. A challenge for future research is to find out the amount of time learners with different characteristics need to spend on the tools in order to reach better performance levels. The use of log files in this dissertation allowed more fine-grained yet challenging results. These results set a direction to further investigate time spent on tools with more granularity. After all, the main aim is to optimize tool use and performance by unraveling the use of tools [49,50].

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