Recommendation Mechanism Based on Students' Working Memory Capacity in Learning Systems*

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***Abstract*—Students' learning performances are susceptible to their cognitive abilities, such as working memory capacity (WMC). WMC is very limited and can be easily overloaded in learning activities that require complex cognitive tasks. This study aims to provide teachers with meaningful recommendations for designing and improving learning contents and learning presentation based on students' WMC. Our previous research successfully detects students' WMC from their learning behaviours in learning systems. This paper proposes the next step of providing meaningful recommendations to the teachers based on different levels of students' WMC. The recommendations are based on the guidelines of cognitive load theory that are intended to assist in presentation of information in order to reduce working memory overload.**

Keywords-learning system, working memory capacity, cognitive load theory, instructional design

I. INTRODUCTION

Humans have a limited working memory (WM) in both capacity and duration to deal with cognitive activities. From the aspect of capacity, WM is capable of holding only about seven (minus/plus two) elements (or chunks) of information for a brief period of time [1]. From the aspect of duration, Driscoll [2] found that new information retained in WM without rehearsal is forgotten after a very short time. The relationship between working memory capacity (WMC) and students' ability to learn showed that students with learning difficulties typically have low WMC, hindering them from remembering crucial information and leading to failure in structured learning activities [3]. According to the cognitive load theory (CLT), the load of WM may be affected by the intrinsic nature of the learning materials, by the presentation of those materials, and by the learning activities students should do [4]. Knowing the levels of students' WMC can help in many ways to enhance learning and teaching in learning systems [5][6]. Teachers can use this information to provide appropriate learning activities to their students. Furthermore, information about students' WMC can be used as input for adaptive systems to provide students with customized learning content and activities to suit their individual WMC. In this paper, we aim to provide teachers with recommendations on how to better support individual students based on their WMC. A recommendation mechanism is therefore built to present meaningful recommendations and suggestions for teachers in order to avoid overload of students' WMC and to enhance the instructional design in learning systems. Based on these recommendations, learning systems provide teachers with suggestions to enhance their learning materials and individually support their students, hence increasing chances for better learning outcomes for students.

The next section presents an overview of previous research on the importance and benefits of providing recommendations based on students' WMC for designing instructional materials. In section 3, the recommendation mechanism based on different levels of WMC is introduced. Section 4 concludes the paper by summarizing the findings and discussing future research directions.

II. RELATED WORKS

Students use their limited WMC to process instructional information for performing learning activities. Information is lost from WM when students are distracted for some reason, such as by irrelevant information [3][4]. Sweller and colleagues [4] argued that if the cognitive load exceeds students' WMC, learning will be impaired. Cognitive load theory (CLT) has emerged as the basis of instructional design guidelines intended to assist in the presentation of information [9]. CLT is an instructional theory based on human cognitive architecture that specifically addresses the limitations of WM under its three categories: intrinsic, extraneous, and germane cognitive loads. Intrinsic load is associated with the nature of presenting the material itself [10]. Extraneous load is related to the activities performed on the presented materials related to the delivery mode (visual or verbal), modality (text or narration), and spatial arrangements on the page or screen [9]. Germane load is associated with processes that assist in learning, including processes facilitating schema construction and automation [9]. For the aspect of classroom learning, the principles of the WM intervention suggested for students with low WMC are to avoid WM failures in order to prevent the student's learning from being delayed and impaired [3]. These principles also enable teachers to monitor students' WM loads and then use some strategies to reduce their loads when necessary. Furthermore, there are a number of strategies in online learning used to allow students to perceive information through different online activities so that the learnt information can be transferred to their WM [12].

III. RECOMMENDATION MECHANISM BASED ON WMC

A. *Concept of Recommendation Mechanism*

The recommendations provided in our mechanism are distinguished based on the level of WMC at which a student

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performs in the learning sessions and are provided to the teachers according to CLT and the features of WM. The recommendation mechanism considers two types of WMC results of a student: the WMC identified in one session (called session WMC) and the total WMC from all sessions. If the session WMC and the total WMC match, it means that the student's learning behaviour is in line with his/her WMC. In such case, the recommendation mechanism does not take any action and does not present any information to the teacher. On the other hand, if the results do not match, it means that the student has probably faced some problems or distractions in that session. When a mismatch is found, further information and recommendations based on the student's WMC are displayed to the teacher. If a student has high total WMC but her/his session WMC is low, the recommended information for high WMC is displayed. If a student has low total WMC but her/his session WMC is high, the recommended information for low WMC is presented.

B. Recommendations based on WMC

Recommendations based on WMC consist of general and recommended information. General information presented to the teachers consists of student, course, and session information. As shown in Table 1, this general information enables teachers to know who, where, and when a student might have problems. The mechanism presents overviews of student and course information to teachers, showing them a list of students who have a mismatch in their session WMC and total WMC, as well as the number of mismatches that each student and each session/course has.

TABLE I. GENERAL RECOMMENDATIONS

{StudentName} who has {TotalWMC} studied in {SectionTitle} of {CourseTitle} since {BeginTime} to {EndTime}, but most of his/her learning actions during this time indicate {SessionWMC}.

The following subsections describe the recommendations based on WMC levels, including a brief discussion on the relationship with cognitive load as well as concrete suggestions for each recommendation.

1) Recommendations for high WMC: The recommendations for high WMC individuals focus on how to guide them effectively to use their WM. In the following subsections, a discussion on the proposed recommendations is presented and the recommendations are shown in Table 2.

a) Increasing learning space: High WMC students are better at discriminating relevant and irrelevant information in their search set [13]. Increasing learning space can lead to extending the search set and therefore, can be helpful for high WMC students to get the most out of the doamin [6].

b) Promoting deep processes: Real-life applications should be used in online learning to help transfer information to students' long term memory by promoting their deep processes [12]. High WMC students have a better ability of using strategies to transfer the knowledge into long-term memory effectively [7]. The variability effect of CLT also encourages students to develop a knowledge structure that aids in transfer of training to similar situations in the real world [8]. Therefore, a teacher should encourage high WMC students to engage in deeper thinking by transferring their knowledge to real life applications.

c) Attending learning activity: Students can use strategies to more efficiently construct a memory connection between the novel information and learned knowledge already stored in long-term memory [12]. Therefore, in a situation where students with high WMC have shown signs of low WMC behaviour, they could be suggested to use additional tools such as mind maps or concept tools to help them connect their new and learned information [14].

d) Using metacognitive skills: Whitebread [15] argued that high WMC individuals have better metacognitive skills about how to learn new knowledge than low WMC individuals. Using metacognive skills is important for students to organise their thinking and to understand their learning processes [14]. Anderson [12] also suggested that students should be encouraged to participate in activites that use their metacognitive skills actively. Therefore, teachers should encourage high WMC students to use their metacognitive skills to think about what happens when they have difficulties in learning, which leads to deep thinking and to understanding of what kind of problems they face.

TABLE II. RECOMMENDATIONS FOR HIGH WMC

Increasing learning space: *"When {StudentName} learns {SectionTitle}, the other sections of {CourseTitle} should also be presented to her/him in order to extend her/his available learning space."*
Promoting deep processes: *"{StudentName} should think about how to apply the learned knowledge of {SectionTitle} of {CourseTitle} in real life. This activity can help her/him in processing information to her/his long-term memory and encourages deeper thinking."*
Attending learning activity: *"{StudentName} should be encouraged to attend a summary activity (such as creation of hierarchical map) after learning {SectionTitle} of {CourseTitle}. This activity will help her/him to connect the main concepts of this section to already learned knowledge."*
Using metacognitive skills: *"{StudentName} should be encouraged to rethink how she/he studied before and compare the differences between learning in {SectionTitle} of {CourseTitle} and previous sections. This will help to use her/his own metacognitive skills to find out what difficulties she/he encountered in {SectionTitle} of {CourseTitle}."*

2) Recommendations for low WMC: The recommendations for low WMC students focus on how to reduce the cognitive load. In the following subsections a discussion on the proposed recommendations is presented and the recommenations are shown in Table 3.

a) Decreasing learning space: Previous studies have argued that low WMC individuals are poorer than high WMC individuals at searching information in a larger search set [7][13]. In order to protect the students from overloading the WM with complex hyperspace structure, the number of navigational path should be decreased [3][6]. Thus, decreasing the learning space into particular parts would reduce the intrinsic load by presenting less information at a time.

b) Rehearsing learned information: Low WMC individuals are not able to keep information in their WM as long as high WMC individuals [13]. Rehearsal would be an effective way to help students remember and transfer the learned information from their WM to the long-term memory [3]. Driscoll argued that novel information in human cognitive system is lost within a very short time without rehearsal [2].

c) Training metacognitive skills: The training of metacognitive skills may help low WMC students in developing an understanding of how to learn and how to think when learning new information [15]. Daley [16] suggested to engage students in the use of mind maps since they are a powerful tool to train metacognitive skills. As such mind maps can help students to better understand their own thinking processes and facilitate connection of new knowledge with learned knowledge [14][16].

d) Preventing overload: Watson and Gable suggested that up to four facts about a learning object can be easily handled in WM [14]. If the number of facts increases, the natural complexity of information increases and the intrinsic cognitive load thus is high. Therefore, a limited number of facts should be provided in order to prevent overload.

e) Using multimedia resources: A previous study suggested to provide more types of multimedia rescources for low WMC students so that they could learn better with various rescources [6]. The modality effect of CLT also suggested that multiple recourses are essential for understanding and learning [8]. Therefore, multimedia resources such as animations and simulations are suggested to be part of the learning experience to facilitate students understanding and help them learn difficult concepts [11].

f) Attracting attention: Low WMC individuals are more likely to have their attention captured by distraction compared to high WMC individuals and thus are also more susceptible to losing focus on the task goal [7]. In CLT, the split attention effect occurs when attention is split between multiple sources of visual information that are all essential for understanding [8]. To help students focus on critical information without distraction of irrelevant information, critical information should be highlighted and be described with additional explanations.

TABLE III. RECOMMENDATIONS FOR LOW WMC

Decreasing learning space: *"When {StudentName} learns {SectionTitle} of {CourseTitle}, the view of presentation should only present the content of this section and no other sections in order to avoid overloading her/his working memory."*
Rehearsing learned information: *"{StudentName} should be encouraged to rehearse {SectionTitle} of {CourseTitle} in order to help her/him retain important information."*
Training metacognitive skills: *"{StudentName} needs some help in developing her/his metacognitive skills. For example, the use of a mind map tool is an excellent way to train metacognitive skills."*
Preventing overload: *"To facilitate efficient process in working memory, {SectionTitle} of {CourseTitle} should present maximum four concepts/ideas."*
Using multimedia resources: *"There are {NumofAnimation} animations and {NumofSimulation} simulations in {SectionTitle} of {CourseTitle}. More animations and simulations could help {StudentName} to better understand and learn this section."*
Attracting attention: *"{StudentName} would benefit from having pointed out the important information in {SectionTitle} of {CourseTitle} again or using different explanations to gain her/his attention."*

IV. CONCLUSIONS AND FUTURE WORKS

Several studies have shown that individual differences in WMC affect students' performances of cognitive tasks [7] [13]. The purpose of this paper is to introduce a mechanism that provides teachers with various recommendations and suggestions based on different levels of students' WMC in learning systems. The proposed recommendation mechanism presents general and recommended information about students' performance to the teachers once it identifies that a student's behaviour in a particular session does not correspond with her/his WMC. Teachers can then use this information to provide appropriate materials and personalized suggestions for students based on their WMC levels. Our future work will focus on extending the proposed mechanism to additionally consider other cognitive abilities, such as inductive reasoning skill, associative skill, and information processing speed.

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