An adaptive Metalearner-based flow: a tool for reducing anxiety and increasing self-regulation

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Abstract

Anxiety and self-regulation are the most common problems among the college student population. There are few attempts found in the literature to promote the development of students' cognitive and metacognitive abilities in online learning environments. In addition, mechanisms for overcoming or reducing individuals' anxiety in a computer-mediated environment is yet to be fully characterized. This study was conducted to investigate the potential of integrating the concept of flow into the design of a Metalearner (MTL) to help reduce anxiety and increase self-regulation among students. The design of MTL was based on the development of adaptive strategies to balance between the challenge of the task and user skills. A total of 260 participants were asked to use the system and respond to an online questionnaire that asked about flow antecedents, experience, and consequences. The structural model results showed that incorporating flow into the design of MTL can help reduce anxiety and improve self-regulation among students. Our findings can be used to enrich students' online learning experience and inform designers and developers of learning systems about the importance of regulating task complexity according to the challenge/skills balance. This would help learners to process the presented information meaningfully and to make the inferences necessary for understanding the learning content.

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1 Introduction

Electronic learning or e-learning has recently received a considerable attention as a way of transforming university teaching and learning (Al-Samarraie et al. 2018; Al-Samarraie and Saeed 2018; Pelet 2019). Current research trends in higher education have outlined the importance of fostering students' understanding in computer-mediated environments (CMEs) (Al-Hatem et al. 2018; Jayachithra 2020; Kim et al. 2014; Tesone et al. 2003). This includes the use of adaptive solutions to help mitigate differences among students, which can have a significant impact on their learning experience and outcomes (Al-Omairi et al. 2020; Al-Samarraie et al. 2017; Maravanyika et al. 2017). The impact of online adaptive systems on learners has been investigated by many previous studies (e.g., Arsovic and Stefanovic, 2020; Ciloglugil and Inceoglu 2018; Santos 2016) where they reported that providing the same learning materials and instructional settings may negatively influence learners' learning as a result of not considering their different learning preferences, styles, skills, and aptitudes. In fact, students' progress in online courses was somehow found to be affected by increased anxiety and reduced self-regulation (Rapp-McCall and Anyikwa 2016; Tavakoli et al. 2020). According to Abdous (2019) and Asikainen et al. (2018), students' anxiety and self-regulation can often be linked to a variety of factors, including a lack of clear instructions and/or feedback. This is why it is argued that developing effective adaptive learning strategies and content to meet individual student needs to be an ongoing issue for platform developers and instructional technologists (Al-Samarraie et al. 2016; Cavanagh et al. 2020; Dziuban et al. 2017; Mirata et al. 2020).

Current debates about the effectiveness of online adaptive systems to promote individuals' online learning experience have motivated many previous researchers (e.g., Albano and Iacono 2019; Eldenfria and Al-Samarraie 2019b; Hassan et al. 2019; Holland 2019) to further investigate how certain learning theories can be incorporated into the design of e-learning as a means to provide simplicity, organization, flexibility, and control (Aldowah et al. 2019a, b; Aldowah et al. 2019a, b; Weber and Hamlaoui 2018). Such concerns have been reinforced recently by numerous studies on the development of adaptive learning strategies and models in an attempt to stimulate individuals' cognition in different online contexts (Eldenfria and Al-Samarraie 2019a, 2019b; Elmunsyah et al. 2020; Imhof et al. 2020; Martin et al. 2020). Other aspects related to the integration of behavioral theories to facilitate certain e-learning activities have also been outlined in the literature (Ghazal et al. 2018; Al-Samarraie et al. 2013; Manian 2020; Rodríguez-Ardura and Meseguer-Artola 2019).

Although previous studies have attempted to develop various adaptive online solutions for different learning needs, current efforts to promote students' flow learning experience in CMEs remain limited. In fact, most adaptive solutions in the context of higher education aims largely at assessing/understanding differences in students' learning in order to provide customized learning materials. However, this does not imply that the calculated scaffoldings/supports are adjusted in accordance to students' learning perceptions of task difficulty and therefore may not positively contribute to learner anxiety and self-regulation. One potential theory that can contribute to the development of online instructions is the flow theory. Flow theory has been widely applied in different contexts to explain individuals' involvement in an activity. It is

also used to explain the influence of certain antecedents on users' experience, and how such experience affects their use of the system (Carlson et al. 2017). As such, the potential of flow theory in the design of e-learning environments has received a considerable attention recently because it emphasizes on the importance of balancing between task challenge and individual skills as an effective way to reduce anxiety (Fullagar et al. 2013).

In CMEs, students' ability to learn is directly influenced by the contrast between the challenge of the task at hand and student skills in meeting those challenges (Rodríguez-Ardura and Meseguer-Artola 2019). However, the lack of knowledge about the role of flow in reducing students' learning anxiety in CME indicates the need for more scientific studies. To fill in this gap, we integrated the concept of flow into the design of an adaptive Metalearner (MTL) in an attempt to help learners to adjust the level of challenge when progressing in the learning task. This study was conducted to answer two research questions: How to incorporate the concept of flow into the design of MTL? What are the relationships between flow antecedents, flow experience, and flow consequences when using MTL? Outcomes from this study can potentially aid the current design and development process of e-learning systems by addressing the impact of the proposed MTL-based flow on individuals' anxiety. This study also provides new avenues of research about the dynamic role of flow in promoting individuals' self-regulation.

2 Literature review

Self-regulated learning is an active and constructive process through which an individual can set goals and monitor and control his/her cognition, motivation, and behavior (Pintrich 2000). A number of studies have been conducted to explore effective measures to stimulate individual self-regulation in different computer-mediated learning settings. For example, Schraw (2007) described the importance for students to regulate their own learning processes, which includes developing specific self-regulated learning abilities in online environments (Reimann and Bannert 2017). In addition, the sequences of learning activities are likely to influence the way in which learners plan, monitor, and reflect on their learning (Wong et al. 2019). This view has been further supported by Bernacki (2017), who suggested the importance of using the time scale on which self-regulated learning occurs, along with other individual events or combinations of events that can be used to reflect such a process. These efforts have largely been successful in producing a number of personalized learning and adaptive learning environments (Peng et al. 2019).

Still, there are several studies (e.g., Ghazal et al. 2020; Roundy et al. 2018; Shute and Zapata-Rivera 2012) that reported the need for tailoring individual learning experiences when using adaptive learning systems. Incoming knowledge has been attributed as the single most important determinant of subsequent learning (Shute and Zapata-Rivera 2007). However, assessing students' incoming knowledge and skills can be difficult to achieve, especially in adaptive learning environments. This can be reasoned to differences in learners' cognitive styles, motivation, and other affective characteristics (McCalla 2004). According to Schunk and Zimmerman (2007), it is very likely

that students might have different self-regulation skills; hence, learning environments could be designed to compensate for and scaffold learners with poor self-regulation while also challenging and advancing learners with good self-regulation. Thus, it can be argued that individual abilities can be readily identified to leverage an ability to support learning while at the same time provide a sense of challenge for learners. This is further explained by Azevedo et al. (2010), who points to the need to adapt several metacognitive processes and make judgments necessary to determine whether learners understand what they are learning, and perhaps modify their plans, goals, strategies, and effort in relation to dynamically changing contextual conditions. The same authors also suggested that future metacognitive tools are lacking the means to effectively emulate the regulatory behaviors of the user by continuously modifying the scaffolding methods in order to promote the self-regulatory behavior of learners. Other studies, such as Kelly and Heffernan (2015) and Van Laer and Elen (2018), have addressed the current difficulties faced by students when learning with adaptive systems. These studies highlighted the lack of providing effective hints and tutoring to help students navigate the new material, which can influence their self-regulated learning. This was also supported by other recent studies (e.g., Hooshyar et al. 2020) that discussed the potential of providing a simple open learner model in helping students edit their learning preferences/needs as they progress in the learning task.

In the current adaptive learning systems, the open learner model can potentially support students' learning through the scaffolding of self-regulated learning processes (Long and Aleven 2017). Learners are provided with the means to set their goal at the start of each lesson and view their achievement and progress after each session (Molenaar et al. 2019). However, the representation of learning activities to support reflection and consequently metacognitive skill need to be conceptually developed by integrating them within a broader theoretical framework in order to yield more insightful results as well as practical uses (Bardone et al. 2020). These challenges have motivated researchers to develop and test a number of mechanisms in an attempt to provide an effective way to promote students' self-regulation pertaining to knowledge, difficulties, and misconception visualization (Hooshyar et al. 2019).

Feedback and scaffolding support have been largely used in the development of previous adaptive/tutoring learning systems. Feedback is a critical component in learning (Koedinger and Corbett 2006; VanLehn et al. 2007). The main issues of using feedback in the development of adaptive systems are the timing and type of feedback. According to Azevedo et al. (2010), timing is important because feedback should be provided soon after one makes an incorrect inference. In addition, scaffolding is another step for stimulating learners' conceptual understanding of a topic and the deployment of self-regulated learning processes (Puntambekar and Hubscher 2005). Assessing students' current knowledge level in relation to providing different types of scaffolding may depend on the amount of time left in a learning session and current sub goal or the overall learning goal for the session. Different scaffolding strategies have been proposed in different forms (e.g., embedded or non-embedded) (Devolder et al. 2012). Embedded scaffolds are commonly used in the development of adaptive systems to attract students' attention to the task, while non-embedded scaffolds are initiated by students themselves (Benz et al. 2007). To date, however, there is no agreement on the effectiveness of self-regulated learning scaffolds. This led researchers to

further investigate the effectiveness of different adaptive learning strategies to develop specific self-regulated learning abilities. For example, Taub et al. (2014) investigated the potential of using a multi-agent learning environment, named MetaTutor, to promote students' self-regulated learning in an online context. MetaTutor used several cognitive and metacognitive processes to help students engage in the online learning process. The design of MetaTutor was based on providing adaptive human scaffolding that can reflect the needs of learners in terms of the content of the domain and the processes of self-regulated learning (Azevedo et al. 2005). Narciss et al. (2007) developed *Study Desks* by using psychological measures in an attempt to enhance active, elaborated, and metacognitive learning activities in a web-based learning environment. The proposed system, however, lacked the tools for promoting specific metacognitive requirements such as selecting and activating learning strategies. Another study conducted by Greene et al. (2013) used two-tiered approach to offer a bridge between the micro-level learning processes (e.g., judgments of learning) and the degree of learners' engagement in the macro-level of self-regulation. The authors have further addressed the challenges in presenting multiple representations with a high degree of learner control. Lajoie et al. (2015) designed an environment for modeling metacognitive activities to support medical reasoning and diagnostics through self-regulation in a medical problem-solving situation. They aimed at helping individuals to progress in the learning process through a series of actions that inform the subsequent ones. The system (Bio-World) provided the necessary functionalities for supporting learners in their cognitive and metacognitive activities. Despite these efforts, we argue that the most promising data-driven interventions are not always efficient in building student capacity through feedback but rather nudge and prompt students to consider and reconsider the strategies they are using, how they are judging their progress and how they make better decisions as they learn (Lodge et al. 2018). Taking this into account, there seems to be limited research on developing and fostering students' adaptive competence through promoting their ability to apply meaningful learned knowledge and skills. This view is supported by De Corte (2019) who suggested the need for developing methods/measures to stimulate the development of individual metacognitive.

In addition to the above, individuals' emotions have also been identified to play a critical role in influencing the learning and problem-solving experience. Learners typically do not accurately monitor and regulate their emotions and may therefore not learn as much, disengage from the task, and not optimize their learning of the instructional material (Alexander et al. 2014). Despite this, the literature revealed a limited number of studies on understanding the role of emotional monitoring and regulation essential in fostering learners' emotion regulation in adaptive learning systems. It is also believed that changes in individuals' emotions can take place when they work toward comprehending difficult materials (Lehman et al. 2012). This view has been further emphasized by Lehman et al. (2012) who points the importance of developing interventions that can enable learners to manage their confusion, so that misconceptions are corrected and conceptual networks are strengthened. Similarly, Lehman (2006) suggest the need for understanding the integration of the cognitive, behavioral, and emotional components of presence into future learning systems. Azevedo et al. (2017), on the other hand, addressed the need for a systematic interdisciplinary research to explore the key connections between emotion regulation-related topics and students'

learning by integrating models, theories, methods, and analytical techniques for effective online learning. Therefore, this study attempts to investigate how the concept of flow can be integrated into the design and development of current adaptive learning environments.

2.1 Flow in computer-mediated environment (CME)

The process of facilitating students' learning flow in online environments has received a little attention by researchers, system designers, and developers. Flow theory implies that by balancing between challenge and skills we can potentially achieve the flow state (Csikszentmihalyi 1988). However, the process of how certain flow antecedents can be used in CMEs is characterized differently in previous studies. For example, Chen et al. (2000a, b) categorized the state of flow into three phases: antecedents, experience, and consequences. Flow antecedents consist of variables that could lead an individual to experience flow. Previous studies have examined many variables from this perspective such as sense of control (Buil et al. 2019; Lee et al. 2018), balance between challenge and skills (Bachen et al. 2016; Larche and Dixon 2020; Tan et al. 2020), and telepresence (Dawoud et al. 2015; Liu 2017; Mahfouz et al. 2020). Flow experience refers to an optimal and pleasurable experience (Stavrou et al. 2015) which is widely explained by certain constructs such as enjoyment (Ettis 2017; Su et al. 2016; Wagner et al. 2020), time distortion (Kim and Ko 2019), focus attention (Turnbull et al. 2019), and concentration on the task at hand (Alp and Sungur 2017). Flow consequences are closely related to individuals' achievement after experiencing the state of flow.

It has been established that finding a balance between challenge and skills can help reduce one's anxiety (Csikszentmihalyi 2014). In addition, promoting self-regulation of online users is commonly linked to the development of their way of thinking and ability to solve difficult tasks (Ader and Erktin 2010; Bradley et al. 2010; Jain and Dowson 2009; Schoenfeld 2016; Shores and Shannon 2007; Villavicencio and Bernardo 2016). In this study, it is proposed that flow experience can result in reduced anxiety and promote self-regulation among students. Still, the literature showed limited evidences about the potential of flow in meeting such expectations in CMEs. Some previous studies asserted the need for linking between behavioral and cognitive processes of individuals in CMEs (Chen and Sun 2016; Weerdmeester et al. 2020). This is why we were motivated to explore the role flow theory in reducing anxiety and improving self-regulation among university students. The development of the proposed MTL is explained in the following section.

3 The proposed system

Being in control provides confidence for an individual to progress in the task (Koufaris 2002; Xu 2007). In addition, sense of control has direct and indirect effects on both flow experience and consequences. Since balancing between challenge and skills has a direct effect on experiencing flow and flow consequences (Csikszentmihalyi 1990;

Finneran and Zhang 2003, 2005; Hoffman and Novak 2009; Nakamura and Csikszent-mihalyi 2002), a tool was developed to customize the complexity of learning tasks by regulating the volume of information and difficulty. Figure 1 shows the main processes used in this study.
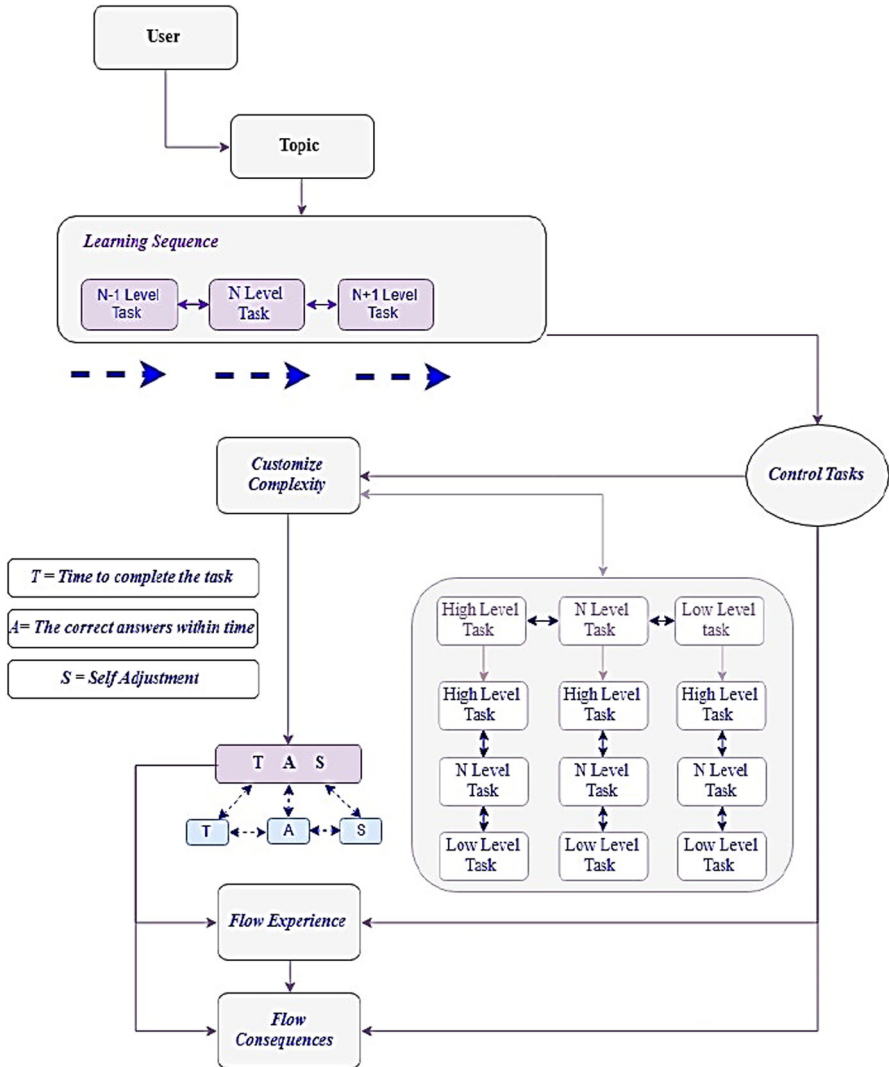

Fig. 1 Flow in the design of MTL

3.1 Customizing complexity

Prior research supported that individuals can tailor their co-created experiences to their specific interests through self-directed customization. Karagiannis and Satratzemi (2016) embedded an adaptive mechanism to Moodle so that the sequence and presentation of the learning task can be adapted to students' learning styles. Moreover, the presentation of the learning task was also adapted to students' knowledge level by the time-based progress calculation and the grade-based progress calculation. Other previous studies (e.g., Eldenfria and Al-Samarraie 2019a, b) proposed a progressive examination of learners' aptitude to continuously adjust the complexity of the learning resources in order to enhance their concentration and emotions. The authors used a domain independent measure to provide the system with clues about the learners' state of knowledge across all learning sessions. Another study by Scheiter et al. (2017) developed a learning environment by tracking students' learning progress through their eye movements to offer them with an assistive or directive adaptivity support. Yadav et al. (2020) proposed an adaptive framework based on a hidden Markov model in an attempt to offer a dynamic user-assistance experience. The authors analyzed the current state of the user to facilitate the prediction of future states. Chen et al. (2019) developed a game-based negotiation mechanism to promote students' learning performance and regulation. Most of the proposed adaptive mechanisms highlighted here are designed based on domain independent measure, intelligent artificial approaches, and biofeedback data. These mechanisms were found to be highly effective in personalizing learners' learning experience. Despite that, most of these mechanisms are limited to predefined threshold as an indication of individuals' performance. This may make it difficult to determine which level of complexity is relevant to learners' current knowledge and competence levels. According to Del Blanco et al. (2012), providing multiple adaptive techniques/tools of learning contents can provide learners with further scaffolding that better suit their learning preferences. Thus, this study argues that providing learners with self-adjustment and system driven modes can enable them to gain more control over the learning task.

The adaptive mechanism proposed in this study differs widely from other previously proposed ones by providing users with two modes of content adaptivity. The first mode known as the self-adjustment mode, which allows the learner to determine the level of task or subject difficulty at the beginning of the learning process. Meanwhile, students in this mode of learning can customize the task complexity level at any stage. The reason for that is because students will have the choice to challenge themselves, especially when the task difficulty is lower than the held skill level of an individual (Ha and Im 2020). The second mode deals with the level of challenge which is customized based on student's progress in the task. In this mode, the system predicts the level of difficulty that best meet individual skills. It also provides suggestions on the level of challenge a student may need to complete the task at hand. This is calculated by aggregating students' performance in previous learning sessions. When a student successfully completes a learning session, the system will gradually increase the level of task difficulty. However, when a student fails to complete a task, the system will reduce the level of task difficulty. After every task, students were provided

with explanatory feedback in the form of hints about incorrect answers as a means to stimulate their interest in the upcoming task till they have completed all the learning task. This type of feedback is considered more effective than corrective feedback as it offers external instructional guidance instead of missing internal mental structures (Moreno and Mayer 2007).

The state of not meeting a desirable or intended objective (failure) was determined by the time taken by the student to complete a task along with the percentage of correct answers. Aspects related to the time and correct answers were also used to assess the level of difficulty for the next task. When a student fails to complete the learning session within the time given by the instructor, the system will offer another task at the same level of difficulty and continue until the student completes the task. The level of difficulty for each task was defined by two experienced instructors (the interrater reliability result was 0.95% of agreement between the raters). The task answers were arranged in a multiple-choice manner with a timer. A blank draft box was also provided to help students note their responses.

3.2 Level of difficulty

This study followed previous recommendations for setting the level of difficulty for the learning tasks. The majority of previous studies on online games used different levels of difficulties (Ijsselsteijn et al. 2007). For example, Kiili et al. (2014) stated that the level of task difficulty can be increased gradually to meet individual's skill level. Falstein (2005) advised that the level of difficulty should be set to incorporate both easy and difficult levels in order to increase users' enjoyment. Chanel et al. (2011) found that easier levels are associated with boredom states due to the low pressure, low arousal, and low motivation; medium levels are associated with higher arousal, pleasure, motivation, and amusement levels; and hard levels are associated with higher anxiety as a result of higher arousal, higher pressure, and lower pleasure. Based on these observations, we assumed that providing three levels of difficulty (easy, medium, and hard) is essential in the development of our system. Figure 2 shows the user interface design of the proposed system. Task complexity in the context of this study refers to students' ability to go beyond the provided information, infer, and make judgments about the meaning and purposes of the learning task (Kumari 2016). The amount of information (textual and visual cues) needed to create the task level structure for each topic was provided based on the knowledge and experience of the subject instructors. The instructors were also responsible for adding the relevant time in which a student needs to answer a given task, according to the level of difficulty.

In addition, a number of multimedia design and cognitive load principles were taken into consideration when designing the proposed system. For example, we attempted to decrease extraneous load (split attention and redundancy) by (1) replacing conventional tasks with completion tasks and (2) replacing multiple sources of information with one integrated source of information that are self-contained. We also attempted to optimize Germane load (self-explanation) by replacing separate worked examples

Fig. 2 The proposed system

with enriched sources that asks learners to self-explain the given information. However, we did not want to manage intrinsic load in the design of the proposed system as this may result in misinterpretation of the actual efficacy of the proposed system.

4 Research model

From a flow theory perspective, it is argued that providing individuals with a challenge that is relevant to their skills would lead them to experiencing a state of flow (Csikszentmihalyi 2014). According to Pearce and Howard (2004), to promote students' learning interest, the learning activity must possess some challenges. Students must be willing to take risks and grow beyond their comfort zone. Risk will only be acceptable when there is sufficient control and telepresence, in addition to balanced skills. In addition, Chen (2000) added that allowing students to manage the level of control given to them in the educational environment can help them perform better at the task at hand. Skadberg and Kimmel (2004) stated that telepresence can act as an antecedent of one's flow experience by providing a virtually mediated environment, which helps separate one's mind from the physical world and provides a peaceful and exciting virtual world (Lee 2018). Based on the previous illustrations, this research considers these dimensions to be the main flow antecedents in this study.

As for flow experience, enjoyment is commonly used to express learners' engagement with activities, as the range of the activity becomes more autotelic, motivating, enjoyable, rewarding, and significant (Chen et al. 2000a, b; Huang et al. 2018; Skadberg and Kimmel 2004). Secondly, a learner's concentration on the task at hand will help them block out the physical world and leave behind irrelevant perceptions and other interfering thoughts (Ang and Mitchell 2017; Chen et al. 2000a, b). Recent studies on flow in CMEs have emphasized on four dimensions: enjoyment, time distortion, focus attention, and concentration on the task at hand. The most common and reliable dimensions that were used to measure flow experience are concentration on the task at hand and enjoyment (Chen, et al. 2000a, b; Delle Fave and Massimini, 2005; Ghani and Deshpande 1994; Hsu and Lu 2004; Koufaris 2002; Lu et al. 2009). Therefore, this study used these dimensions as the main driver of one's flow experience.

Both anxiety and self-regulation of students were used as the main dimensions of flow consequences in this study. It has already been established by Csikszentmihalyi (2014) that individual's level of anxiety can be influenced by their flow experience. Self-regulation theory is also consistent with this understanding, in addition to its focus on the idea that goals, plans and feedback are relevant parameters for regulating one's actions (Zimmerman 2002). It is one of several theories that make a distinction between cognitive and emotional processes. Based on these, it can be argued that incorporating the relevant antecedents in the design of e-learning systems can help users achieve the state of flow and thus reducing anxiety and promoting self-regulation among students. The relationships between these variables are explained in the following section.

4.1 Study hypotheses

Past studies on the effect of perceived control on individual's increased enjoyment in CMEs have shown how individuals' feeling of control over a task can result in an enjoyable experience (Chen et al. 2000a, b; Ghani and Deshpande 1994; Nakamura and Csikszentmihalyi 2009). Zaman et al. (2010) and Rogers et al. (2016) stated that when individuals' sense of control increases while performing a task, they are likely to enjoy the task and concentrate more. Several researchers, like Ghani et al. (1991), demonstrated how perceived control can positively influence the experience of an individual. Zaman et al. (2010) hypothesized that perceived control can be positively contribute to flow experience in terms of enjoyment and concentration.

Other previous studies on flow (e.g., Kaur et al. 2016; Mathwick and Rigdon 2004; Pearce et al. 2005) have reported a direct relation between perceived control and concentration of individuals on the task at hand. Perceived control allows an individual the ability to predict the consequences of certain events or actions, which can potentially reduce anxiety (Daniels et al. 2006). Previous studies have reported the theoretical relation between perceived control and anxiety in relation to specific events (Gregor and Zvolensky 2008; Rosenbaum et al. 2012). Thus, the following hypotheses were proposed for this study:

H$_{1a}$ Sense of control has a positive relationship with enjoyment.

H$_{1b}$ Sense of control has a positive relationship with concentration on the task at hand.

H$_{1c}$ Sense of control has a positive relationship with reduced anxiety.

The relationship between telepresence and flow experience in terms of enjoyment and concentration have been widely investigated in the literature. For example, Guo et al. (2016) and Pelet et al. (2017) hypothesized that telepresence can positively influence individual enjoyment in virtual worlds. Other previous studies (e.g., Novak et al. 2000; Pelet et al. 2017; Weibel et al. 2008; Yim et al. 2012) acknowledged the positive impact of telepresence when experiencing concentration on the task at hand within CME. From the flow theory perspective, an individual may experience anxiety when the challenge level is high and the skill level is low. This state may negatively influence learners' performance and lead to a negative learning experience (Csikszentmihalyi 1990; Nakamura and Csikszentmihalyi 2002, 2009). According to the original understanding of flow theory and evidence from previous studies, this study hypothesized the following:

H$_{2a}$ Telepresence has a positive relationship with enjoyment.

H$_{2b}$ Telepresence has a positive relationship with concentration on the task at hand.

According to Csikszentmihalyi (2000), enjoyment appears on the border between boredom and anxiety; it occurs when learning challenges are balanced with the person's capacities and skills. Furthermore, Csikszentmihalyi (1997) declared that flow experience and sense of enjoyment may occur when there is a balance between challenge and skills. This assumption was used in this study to construct the direct relationship

between enjoyment and skills-challenge balance. In addition, several studies have referred to the positive effect that skills-challenge balance has on individual's concentration on the task at hand (Finneran and Zhang 2005; Guo et al. 2016; Hoffman and Novak 2009; Kiili et al. 2014; Lin and Joe 2012; Pace 2004; Pelet et al. 2017; Zaman et al. 2010), hence leading to the following hypotheses:

H₃ₐ The balance between challenge and skills has a positive relationship with enjoyment.

H₃ᵦ The balance between challenge and skills has a positive relationship with concentration on the task at hand.

H₃ᵧ The balance between challenge and skills has a positive relationship with reduced anxiety.

Our review also showed that some previous studies have used different dimensions to describe flow experience, but they did not disregard enjoyment, due to the previously mentioned importance of enjoyment. According to Koufaris (2002), flow may consist of intrinsic enjoyment, perceived control, and concentration. In addition, some researchers have reported the potential impact of enjoyment on individuals' concentration when performing a task (Hausman and Siekpe 2009; Lu et al. 2009; Zaman et al. 2010). This led us to argue that increasing individuals' level of enjoyment can help reduce their anxiety in CME. The findings of Brantmeier (2005) suggest that self-assessment and enjoyment may offer insights about the association between metacognition and anxiety in reading. Based on these, the following hypotheses were proposed:

H₄ₐ Enjoyment has a positive relationship with concentration on the task at hand.

H₄ᵦ Enjoyment has a positive relationship with reduced anxiety.

H₄ᵧ Enjoyment has a positive relationship with self-regulation.

Our review of the literature showed an immense lack of discussion regarding the effect of flow experience on individual's anxiety in CME. Since experiencing flow can be signified by enjoyment and concentration on the task at hand, these dimensions may, as a result, reduce anxiety. Chen et al. (2000a, b) defined flow as an optimal and enjoyable experience that occurs when an individual engages in any activity with full involvement, concentration, and enjoyment. Based on the positive qualities of flow, the direct impact of enjoyment and concentration on the task at hand is believed to reduce one's feelings of anxiety in CME. Here, we argued that when an individual is fully immersed with an activity, he or she will less likely experience anxiety. In addition, individual's level of concentration on the task has been attributed as one of the possible promoters of self-regulation in CME (Jamaris and Hartati 2017; Jantz 2010; Kuhl et al. 2006). Based on these assumptions, this study hypothesized the following:

H₅ₐ Concentration on the task at hand has a positive relationship with reduced anxiety.

H₅ᵦ Concentration on the task at hand has a positive relationship with self-regulation.

Harvey (2004) noticed that the level of metacognition an individual possesses can be affected by individuals' anxiety. Other researchers showed how the process of self-regulation can positively contribute to individual's level of anxiety (Wells 2002, 2005, 2010). Moreover, some studies have proposed that anxiety can affect both general metacognitive and self-regulatory processes (Bacow et al. 2010; Lysaker et al. 2011; Matthews et al. 2000; Normann et al. 2014; Veeraraghavan 2009). As such, we proposed the following:

H₆ Reduced anxiety has a positive relationship with self-regulation.

5 Method

A questionnaire approach was used in this study to examine the proposed hypotheses.

5.1 Sample

The sample of this study was restricted to 300 undergraduate math students from one public university in a developing country. A convenience sampling method was used to recruit students from year one and year two. Although students from early years might not have had the opportunity to take all the courses in the curriculum, their learning experience with MTL-based flow was the main focus here.

5.2 Instrument

The instrument used in this study was adapted from well-known and validated previous instruments (see Supplementary, Table 1). Items for measuring sense of control were adapted from Ghani and Deshpande (1994) and Fang et al. (2013) to measure students' sense of control while performing an activity as well as their feelings about the surrounding environment. Individual's level of skills was measured with items adapted from Novak et al. (2000). Level of challenge was assessed in this study using items that were adapted from Novak et al. (2000) and Fang et al. (2013). This study adapted items from Novak et al. (2000) to measure telepresence. In addition, items developed by Ghani and Deshpande (1994) were used in this study to measure students' perceptions of their engagement and enjoyment with a specific task within a computerized environment. We also adapted items from Ghani and Deshpande (1994) to measure the amplitude of participants' involvement. These items can assess whether or not the participants' minds are completely focused with the task at hand and their perception of the physical world is totally blocked out.

As for anxiety, this study adopted items that measures the anxiety level from the Motivated Strategies for Learning Questionnaire (MSLQ), which is a self-report instrument used to assess college students' motivational orientations and uses of different learning strategies (Pintrich 1991). This study employed the motivational aspects of MSLQ in order to measure students' anxiety while using the proposed system. We

also used items from MSLQ to measure participants' ambition regarding metacognitive self-regulation (planning, monitoring, and regulating). A seven Likert-scale (1 = I totally agree; 7 = I totally disagree) was used to measure all the dimensions of this study. A pilot study was carried out among 35 undergraduate students. A questionnaire sheets were distributed to all these 35 participants. The main purpose of the pilot study was to determine the reliability of the questionnaire's items. The average Cronbach's alpha coefficient value was 0.76 (ranged from 0.71 to 0.83), which exceeds the conventional, suggested cutoff criterion of 0.70 (Nunnally, 1978).

5.3 Procedure

Early years mathematics students were asked to participate in this study. The expected learning outcomes were to improve students' mathematic learning and understanding in terms of: (1) Describing the basic concepts of linear algebra; (2) performing operations on matrices and vectors; (3) solving a linear system using inverse of matrix, Cramer's rule, and Gauss; (4) proving the basic results of vector space by analyzing the solution of a linear system; and (5) solving complicated problems within the linear system. We demonstrated to the students, with the help of four instructors, the objectives of this study and how to use the proposed system. The instructors were asked to encourage their students to participate in this study by offering carry marks as a recognition for their participation in the study. Students were asked to use the proposed system on their own. All students were asked to register and solve multiple learning tasks linked to the weekly topics on the subject. Log data were used to understand students' access and completion of the learning tasks. The students were asked to use the system for two weeks. After two weeks of active use of the system (on daily basis) were invited to respond to an anonymous online survey about their perceptions of the factors influencing their flow experience.

6 Results

A total of 300 questionnaires were originally distributed to undergraduate students from one public university. A total of 283 questionnaires were returned. Out of the 283 responses, 23 questionnaires were discarded due to some missing values found during the data screening phase. The remaining 260 questionnaires were used for further analysis. With a response rate of 86.6%, it can be said that the number of gathered responses were relatively sufficient. 59.3% of respondents were female and 40.7% were male. In addition, 95.5% of students were between 18 and 22 years old, while only 4.5% of respondents were between 23 and 27 years.

6.1 Assessment of the measurement model

6.1.1 Convergent validity

The proposed model was convergent because of the high item loadings (greater than or equal to 0.5) on their associated latent variables. The average variance extracted (AVE) was used to measure the convergent validity of each latent variable. The AVE scores indicated that all the constructs had reached the minimum cutoff which is 0.50 AVE (see Table 1). We also assessed the reliability of each construct using composite reliability (CR) and Cronbach's alpha, which were found to be higher than the recommended value of 0.70. For each of the latent variables ranged from 0.878 to 0.946; this suggests an adequate internal consistency reliability of the measures (Alzahrani et al. 2012; Hair et al. 2011) (see Supplementary, Table 2 for cross loading results).

6.1.2 Discriminant validity

We measured the discriminant validity using the square root of AVE. In doing so, the correlations between latent constructs were compared with its square roots of average variance extracted (Fornell and Larcker 1981). The discriminant validity was assessed following the criterion by Fornell and Larcker (1981), which suggested that the square root of the AVE must be higher than the correlations between the latent variables. Table 2 indicates that the square roots of average variance extracted were higher than the correlations between the model constructs.

6.2 Assessment of the structural model

This study assessed the R^2 values, hypotheses testing, test for unobserved heterogeneity), and the predictive relevance.

6.2.1 Assessment of variance explained ($R.^2$)

Hair et al. (2011, p. 147) argued that: "The primary evaluation criteria for the structural model are the R^2 measures and the level of significance of the path coefficients". R^2 values of 0.20 are considered high in disciplines such as consumer behavior, R^2 values of 0.75 are considered high in other studies. In the present study, the explained variance through the interaction relationship was 0.49, which can be perceived as a moderate value (see Fig. 3).

6.2.2 Hypothesis testing

This study applied the standard bootstrapping procedure to test the significance of the proposed hypotheses. Figure 4 presents the structural model and hypotheses testing results using the t-statistics. The t-values for the one-tailed test were 1.645 (with a significance level of 10%), 1.96 (with a significance level of 5%), and 2.58 (with a significance level of 1%). Table 3 shows the hypotheses testing results. Ten out of the

Table 1 Factor loadings, Cronbach's alpha, CR, and AVE results

Constructs	Loading	Cronbach's alpha	CR	AVE
Sense of control (SC)		0.946	0.961	0.86
SC2	0.88			
SC3	0.91			
SC4	0.89			
Skills-challenge balance (BCS)		0.936	0.945	0.64
BCS 3	0.73			
BCS 4	0.80			
BCS 5	0.80			
BCS 6	0.72			
BCS 7	0.77			
BCS 8	0.83			
BCS 9	0.79			
BCS 10	0.83			
BCS 11	0.85			
BCS 12	0.80			
Telepresence (TELE)		0.945	0.96	0.86
TELE1	0.85			
TELE2	0.91			
TELE3	0.84			
TELE4	0.75			
TELE6	0.72			
Enjoyment (ENJ)		0.878	0.918	0.74
ENJ1	0.88			
ENJ2	0.92			
ENJ3	0.71			
ENJ4	0.90			
Concentration (CAT)		0.881	0.926	0.81
CAT1	0.91			
CAT2	0.93			
CAT3	0.92			
CAT4	0.92			
Reduced anxiety (ANX)		0.926	0.938	0.60
ANX1	0.94			
ANX2	0.92			
ANX3	0.91			
ANX4	0.92			

Table 1 (continued)

Constructs	Loading	Cronbach's alpha	CR	AVE
Self-regulation (SR)		0.879	0.912	0.68
SR2	0.71			
SR3	0.79			
SR4	0.71			
SR5	0.79			
SR6	0.82			
SR8	0.78			
SR9	0.75			
SR10	0.80			
SR11	0.79			
SR12	0.76			

Table 2 Discriminant validity results

Construct	ANX	BCS	CAT	ENJ	SC	SR	TELE
ANX	**0.928**						
BCS	0.464	**0.798**					
CAT	0.274	0.287	**0.926**				
ENJ	0.444	0.271	0.22	**0.859**			
SC	0.421	0.676	0.223	0.612	**0.898**		
SR	0.482	0.689	0.189	0.673	0.594	**0.776**	
TELE	0.309	0.649	0.203	0.62	0.421	0.545	**0.823**

The diagonal values (bold) represent the square root of AVE shared between the constructs

fourteen relationships were significant.

The results showed that sense of control relates positively to the level of enjoyment ($\beta = 0.139$; $t = 2.245$) and reduced anxiety ($\beta = 0.162$; $t = 2.107$). However, the results reported an insignificant association between sense of control and concentration on task at hand ($\beta = 0.062$; $t = 0.672$). The results indicated that telepresence positively associated with enjoyment ($\beta = 0.178$; $t = 2.493$). The proposed relationship between telepresence and concentration on task at hand was not significant ($\beta = 0.039$; $t = 0.486$).

The results revealed that the balance between challenges and skills was positively associated with students' reduced anxiety ($\beta = 0.187$; $t = 1.916$), enjoyment ($\beta = 0.590$; $t = 7.223$) and concentration ($\beta = 0.262$; $t = 1.808$). The analysis showed insignificant association between enjoyment and concentration ($\beta = -0.51$; $t = 0.476$). It was also found that enjoyment can significantly reduce student anxiety ($\beta = 0.163$; $t = 1.755$). The relationship between enjoyment and self-regulation was significant
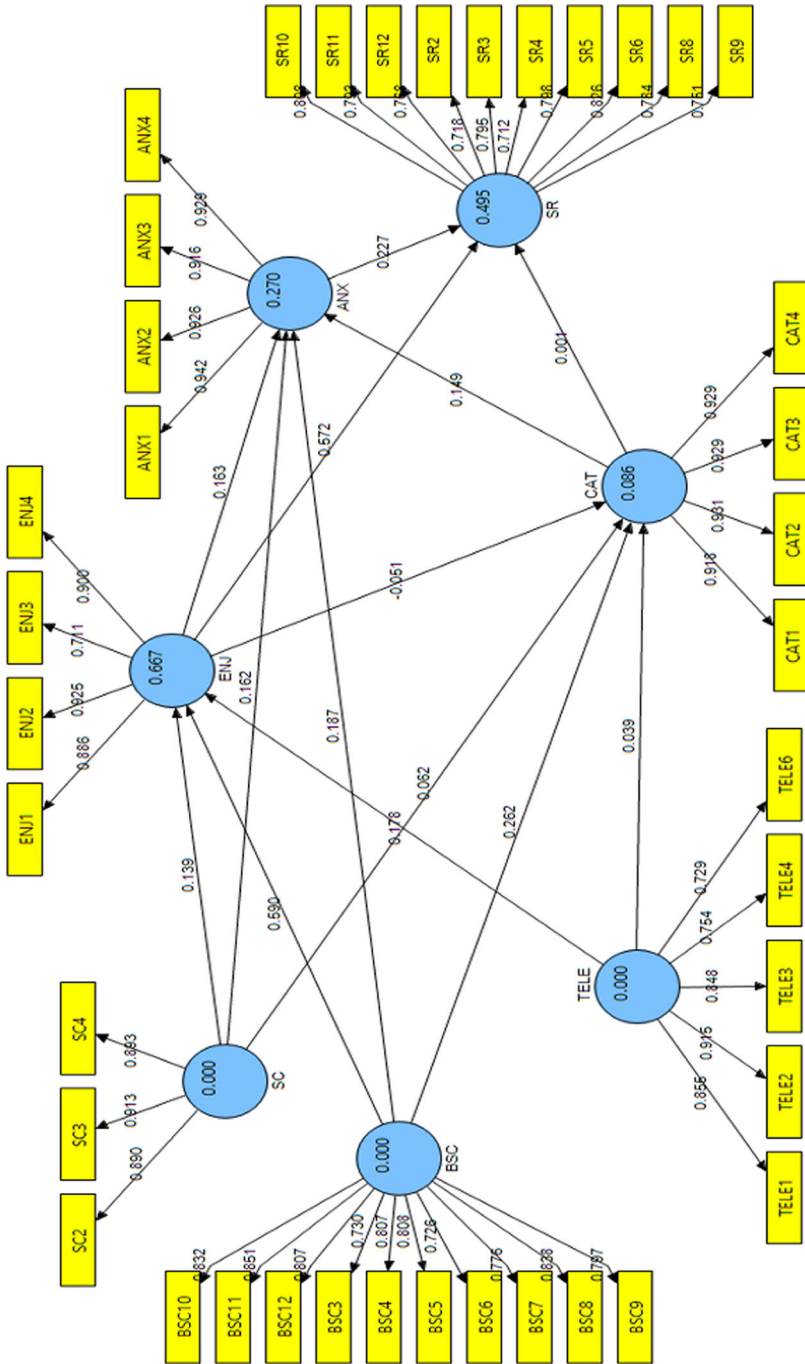
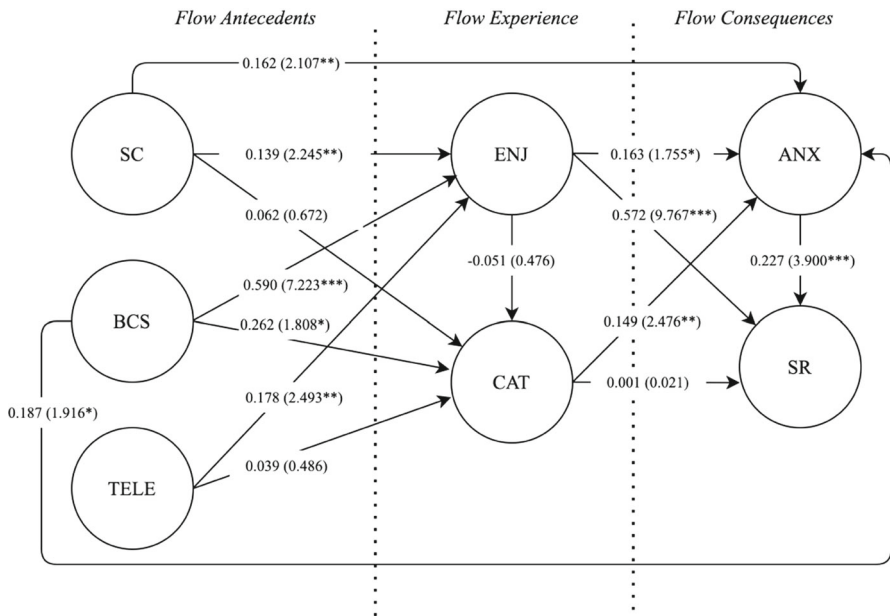**Fig. 3** Variance explained through the direct relationship

Fig. 4 Path coefficient and t value. Sense of control (SC); Balance between challenge and skills (BCS); Telepresence (TELE); Enjoyment (ENJ); Concentration on task at hand (CAT); Reduced anxiety (ANX); and Self-regulation (SR)

Table 3 Hypotheses testing results

Hypotheses	Path coefficient	Mean	St.D	T value	Decision
H_{1a} (SC → ENJ)	0.139	0.144	0.049	2.245**	Supported
H_{1b} (SC → CAT)	0.062	0.06	0.069	0.672	Not Supported
H_{1c} (SC → ANX)	0.162	0.159	0.06	2.107**	Supported
H_{2a} (TELE → ENJ)	0.178	0.182	0.056	2.493**	Supported
H_{2b} (TELE → CAT)	0.039	0.041	0.06	0.486	Not Supported
H_{3a} (BSC → ENJ)	0.590	0.583	0.065	7.223***	Supported
H_{3b} (BSC → CAT)	0.262	0.191	0.081	1.808*	Supported
H_{3c} (BSC → ANX)	0.187	0.258	0.096	1.916*	Supported
H_{4a} (ENJ → CAT)	− 0.051	0.05	0.083	0.476	Not Supported
H_{4b} (ENJ → ANX)	0.163	0.162	0.075	1.755*	Supported
H_{4c} (ENJ → SR)	0.572	0.573	0.045	9.767***	Supported
H_{5a} (CAT → ANX)	0.149	0.15	0.049	2.476**	Supported
H_{5b} (CAT → SR)	0.001	0.002	0.041	0.021	Not Supported
H_6 (ANX → SR)	0.227	0.227	0.046	3.900***	Supported

$* P \leq 0.05$; $** P \leq 0.01$; $*** P \leq 0.001$

Table 4 Construct cross-validated redundancy

Constructs	SSO	SSE	1-SSE/SSO
ENJ	984	511.41765	0.480267
CON	984	919.17814	0.065876
ANX	984	766.64757	0.220887
SR	1230	879.84013	0.284683

($\beta = 0.572$; t = 9.767). Moreover, the relationship between concentration on task at hand and reduced anxiety was positively significant ($\beta = 0.149$; t = 2.476). In contrast, insignificant and very weak relationship between concentration and self-regulation was found ($\beta = 0.001$; t = 0.021). Finally, there was a significant relationship between reduced anxiety and self-regulation ($\beta = 0.227$; t = 3.900). Table 3 shows the relationships between result with its path coefficients, mean, standard deviation, and t value.

6.2.3 Predictive relevance Q^2

A blindfolding criterion was used to calculate the cross and communality validated redundancy. In addition, Q^2 was also used to estimate the extent to which the model can predict the data of omitted cases (called predictive relevance). According to Fernandes (2012), the Stone-Geisser test can be calculated by the following formula: $Q^2 = 1\text{-SSE/SSO}$ where blindfolding is also used to estimate Q^2. Based on the suggestions of previous studies, we used 7 as a distance value for d to calculate the cross-validated redundancy for each dependent variable. Table 4 shows that the estimated cross-validated redundancy measures for enjoyment, concentration on task at hand, reduced anxiety and self-regulation were found to be 0.428, 0.279 and 0.362, respectively. This result supports the assumption that the measurement and structural model have a sufficient prediction quality.

7 Discussion and implications

Learning with MTL was found to offer a significant control for students by allowing them to control the difficulty of the learning task. We found that e-learning-based flow antecedents have contributed to students' learning through providing autotelic, motivational, enjoyable, and intrinsic learning experience. The current research findings appears to be relevant to the work of Zaman et al. (2010) who stated that when an individual's sense of control increases while performing a task, he or she is likely to enjoy the task and concentrate more. Some studies, such as Rogers et al. (2016), reported that students who perceive the environment to provide the required elements of control will likely experience a higher level of enjoyment. We found that students' sense of control while using MTL had no positive relationship with their concentration on the task at hand. Despite the fact that few researches, such as Kaur et al. (2016), stated that sense of control in CMEs can stimulate students' concentration, there is still limited evidence to support this finding.

Our results showed a positive relationship between sense of control and students' reduced anxiety. Improving students' control through helping them to recognize and understand the task may have contributed to their anxiety by actively engaging with the learning process. The current findings are in line with some previous studies that reported the theoretical relation between perceived control and reduced anxiety of individuals (Gregor and Zvolensky 2008; Rosenbaum et al. 2012). Telepresence is another key antecedent of flow that we examined. The results showed a positive perception among students about their sense of telepresence while using MTL. The effect of telepresence on individuals' enjoyment and tendency to engage in online learning activities has been widely identified as one of the major concerns of educational decision makers. For example, when students are engaged in a constructed online world, they are likely to lose self-awareness and perceive a sense of belongingness. The result of this study is relevant with previous studies such as Pelet et al. (2017) that highlighted the direct influence of telepresence on enjoyment and concentration.

We found no relationship between telepresence and students' level of concentration on the task at hand. This can be reasoned to the fact that maintaining individuals' telepresence in CME may not necessarily increase their concentration on the task. In addition, when students experience a feeling of being in another place, then they are likely to feel less disturbed by the physical environment, which leads to enhanced user experience. However, this finding is not in line with other previous studies (e.g., Novak et al. 2000; Pelet et al. 2017; Weibel et al. 2008; Yim et al. 2012) which have reported a notable effect of telepresence on promoting the students' flow experience in general. The relationship between the balance between challenge and skills and students' reduced anxiety was significant. It is assumed that enabling students to regulate the challenge of the task may have provided them with the convenient instinctive psychological needs that makes them more competent. This includes making the students capable of handling complex materials and gain the confidence to complete the task at hand without being anxious about making mistakes. We also found a significant relationship between challenge/skills balance and students' enjoyment. It is believed that MTL might have facilitated students' customization of the task complexity which, as a result, raised their interest and enjoyment in learning. The same was reported for

the relationship between challenge/skills balance and students' concentration. This can be linked to the feasibility that when a student receives the suitable challenge to his/her skills, he/she will likely be able to pay more attention to the task at hand. These results are relevant to the previous findings of Guo et al. (2016) who declared that the balance between challenge and skills is an antecedent that would increase online learners' enjoyment and level of concentration.

MTL offered an enjoyable experience to the students, particularly by providing them with an enjoyable learning experience. Yet, these experiences had no significant impact on students' concentration. This can be due to that system enjoyment may not necessarily predict individuals' cognitive reflection in CME. Previous studies have mentioned that enjoyment and concentration on the task at hand are not only essential for a person to experience flow, but they are also useful for achieving flow consequences in CMEs (Guo et al. 2016; Hausman and Siekpe 2009; Hwang and Kim 2007; Lu et al. 2009; Nah et al. 2011; Pelet et al. 2017; Zaman et al. 2010). Students who perceived learning with MTL enjoyable are believed to have experienced a reduction in their anxiety state. It is a well-known fact that enjoyment and anxiety are user's affective variables in which reducing anxiety can results in an improvement in performance. This may be why students have perceived their sense of enjoyment as a key to reduce their anxiety regardless of their flow states (Agarwal and Karahanna 2000).

The present study found that experiencing enjoyment can increase students' self-regulation. This can be attributed to the role of MTL in facilitating a more comprehensive and effective learning atmosphere that provided the cognitive resources required for students to effectively plan, monitor and regulate their thinking. This finding is in line with the work of Wang et al. (2011), which showed the potential of post-project work enjoyment in predicting individuals' self-regulation. We also found a positive relationship between students' concentration and reduction in their anxiety level. Csikszentmihalyi (1990) stated that flow usually occurs when there is a balance between challenge and skills through which an individual becomes able to concentrate on the task at hand and enjoy it. Yet, there is an immense lack of knowledge about the effect of using flow in designing online learning systems and its role in reducing anxiety in CME. This result offers a new evidence about the importance of integrating flow into designing online learning systems in order to maintain students' concentration essential for anxiety reduction.

The results regarding the relationship between students' concentration and their self-regulation was not significant. This is possible due to the neglected role of concentration, as a concept, and individuals' self-regulation that does not necessarily require attentional resources. In addition, the act of self-regulation does not occur without the interaction of the individual with the environment (Zheng et al. 2020), which is why students may not perceive their concentration to emulates their self-regulation development in CME. This result may offer new insights into the role of incorporating flow into the design of e-learning and its role in stimulating an individual's self-regulation. This finding adds to the work of Beilock et al. (2002) who stated that skill-focused attention may not always be detrimental to well-learned performances. As for the relationship between reduced anxiety and self-regulation, this study found a significant result. This includes making students feel better about their abilities to plan, monitor, and regulate their learning progress. Some studies have proposed that anxiety can

affect both general metacognitive and self-regulatory processes (Bacow et al. 2010; Lysaker et al. 2011; Matthews et al. 2000; Normann et al. 2014; Veeraraghavan 2009).

The results of this study differ somewhat from that of other authors (e.g., Azevedo et al. 2005; Narciss et al. 2007; Taub et al. 2014) in that incorporating flow into the design of MTL was found to significantly reduce learners' level of anxiety, which as a result increased their self-regulated learning processes. This work also adds to the call by dos Santos et al. (2018) to propose specific mechanisms for allowing learners to adjust their flow state in the context of adaptive learning. The results of this study contributes to the current literature on adaptive learning systems (e.g., Greene et al. 2013; Lajoie et al. 2015) regarding the potential of adding elements of self-control, such as the ability to adjust the difficulty of a learning task, in facilitating learners' enjoyment and concentration. The sequencing of learning resources in this study extends previous works (e.g., Flores et al. 2019; Rachmatullah et al. 2021; Sahid et al. 2020) by showing the effectiveness of flow theory in customizing task complexity through students' manual self-adjustment and actual progress in the task.

This study offers new evidence about the role of flow in e-learning development to reduce anxiety and increase self-regulation of students in online learning. This knowledge is relatively new and opens a promising avenue in CME-based flow studies. Our findings can be used as the basis for promoting students' online learning of complex tasks. It can be also used to inform designers and developers of learning systems about the importance of regulating task complexity according to the task challenge and individual's skills. This would help learners to process the presented information meaningfully and to make the inferences necessary for understanding the learning content. In addition, the proposed MTL can support online learners by balancing the level of challenge with their skills; provide a method of reducing students' anxiety to learn complex materials; promote students' metacognitive and self-regulatory abilities; and provide future research with the necessary guidelines related to the use of flow theory in designing and developing online learning systems.

8 Limitations and future works

Despite the study design and findings, there are still some limitations that can be tackled in future research. First, this study identified that students were requested to explore the contents provided by the system without considering their learning style, which may lead to certain learning preferences. Second, the design of the system was mainly to help students learn about mathematics in which future studies may consider using other learning subjects or domains. Third, other possible negative effects (e.g., increase in cog load when students have to decide on difficulty level at each step) were not examined in this study. Fourth, certain flow-related antecedents and relationships were examined in this study whereas the impact of other antecedents (e.g., vividness) and relationships (e.g., the link between: sense of control and self-regulation; challenge/skills balance and self-regulation; and telepresence with anxiety and self-regulation) were not considered due to the limited evidence available in the literature. This means that future studies can potentially explore how other flow antecedents may contribute to the learning experience of students in CME. Meanwhile, future studies

may also consider comparing the efficiency of the proposed system with other learning methods and how experiences emerged from such processes can contribute to the development of students' thinking skills. The use of timing data in this study was limited to predicting the complexity of the upcoming learning task. Future work may also consider using timing data as a proxy for predicting respondent attention and the correctness of answers to mathematics problems. Since the learning task was limited to essay-type and multiple-choice math questions, the findings of this study cannot be generalized to other domains. Thus, it is essential to further investigate the effectiveness of these questions in domains that require proportional reasoning. Meanwhile, the feedback was limited to the content and the style of the answers (e.g., internalized the knowledge and ability to answer the math problems), and, therefore, future studies should focus on how the generated feedback can be adaptive based on students' current states of knowledge. In addition, although the adapted self-reported measures demonstrated good internal consistency, they may not accurately capture the full experience of students when learning with MTL. Finally, future studies may focus on triangulating several qualitative and quantitative measures of individual learners' experience (e.g., interest and time distortion) and learning consequences (e.g., increased learning, creativity, and exploratory mindset).

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