

This chapter describes how multimedia design principles, such as the multimedia, personalization, and generative activity principles, used in computer-based learning environments facilitates students self-regulated learning.

A Multimedia Learning Theory-Informed Perspective on Self-Regulated Learning

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One-sentence abstract: In this chapter, we describe how multimedia design principles, such as the multimedia, personalization, and generative activity principles, used in computer-based learning environments facilitates students self-regulated learning.

Two-sentence abstract: Higher education instructors are increasingly using computer-based learning environments to convey content, but many students struggle to learn effectively with them. In this chapter, we describe how students' ability to successfully self-regulate their learning in computer-based learning environments can be enhanced by designing those environments according to the principles of the cognitive theory of multimedia learning.

Traditional abstract: The affordances of computer-based learning environments make them powerful tools for conveying information in higher education. However, to most effectively use these environments, students must be adept at self-regulating their learning. This self-regulation is effortful, including a myriad of processes including defining tasks, making plans, using and monitoring the efficacy of high-quality learning strategies, and reflecting on the process and outcomes of learning. Therefore, higher education instructors and course designers should design computer-based learning environments in ways that ease learning and free up mental resources for self-regulation. In this chapter, we describe how design principles from the cognitive theory of multimedia learning can facilitate learning in computer-based learning environments and subsequently promote self-regulated learning. Examples of the *multimedia*, *personalization*, and *generative activity principles* are presented to show how the cognitive theory of multimedia learning can guide design and promote students' selection, organization, and integration of content, resulting in better understanding and more mental resources available for self-regulated learning and the deeper learning it can afford.

Introduction

Learning in computer-based learning environments (CBLEs) has become increasingly common in higher education, even in courses where face-to-face instruction is the primary medium for learning. Most CBLEs are *multimedia learning environments*: environments in which learners must integrate verbal and visual information to learn effectively (Mayer & Fiorella 2021). For

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example, organic chemistry instructors use Khan Academy videos to teach the complexities involved in substitution reactions, editors dedicate significant amounts of space in eTextbooks for graphs that portray limits in calculus, and cultural anthropology instructors include authentic images in their slides when lecturing about the engineering used to build the Great Pyramid of Giza. Although these multimedia CBLEs provide students with rich learning experiences, they also pose challenges for students because they might lack opportunities for direct interaction with instructors. Their positioning within both digital and physical environments means they are often riddled with distractors. Insight from key learning theories can help instructors leverage the strengths of multimedia CBLEs while limiting or helping students manage the challenges. Yet, much of the prior research and translations to practice on learning in CBLEs are not grounded in an explicit model of learning (Castañeda & Selwyn 2018). In this chapter, we propose that an essential theory through which we can understand learning in multimedia CBLEs is self-regulated learning (SRL) and SRL in multimedia CBLEs is further informed by evidence-based design principles established by the cognitive theory of multimedia learning (CTML; Mayer & Fiorella 2021).

Self-regulated learning is an adaptive process in which students set goals, make plans, and actively monitor and control their cognition, behavior, motivation, affect, and context to achieve those goals (Greene 2018). Take, for example, a student watching an online video lecture in their biology course. The student knows the content being taught in the video will be tested on the next course exam, and they have a goal to earn a high grade on that exam to make up for the poorer grade they earned on the last exam. Accordingly, the student is watching the video intently while taking notes on the important concepts. They also pause the video to draw an example of one of the more complex concepts, and then they rewind the video to review the

explanation of the complicated concept again. This student is using the goal of earning a good grade on the exam to motivate their enactment of strategies (for example, taking notes) and adaptation of strategies (for example, drawing an example). They also use metacognitive judgments of their learning to rewind and review complicated concepts. In this example, the student is effectively self-regulating their learning, but such processing is not typical. Instead, many students struggle to self-regulate their learning effectively in CBLEs (Azevedo & Dever 2021).

One way to maximize the affordances of multimedia CBLEs for promoting SRL is to design them according to the CTML (Mayer & Fiorella 2021), which substantiates that integrating verbal and visual information helps students to construct a coherent mental model during learning. Multimedia environments support mental model construction because they help students to *select* the most important information from verbal and visual content, *organize* the information in each of those modalities into a coherent mental model, and *integrate* that model with their prior knowledge (SOI). Research has also established principles for designing multimedia CBLEs that are most likely to support mental model construction through SOI, including the *multimedia*, *personalization*, and *generative activity principles*. The *multimedia principle* is the foundational design principle in multimedia learning and suggests that students construct higher quality mental models when they integrate verbal and visual information during learning (Kuhlmann & Fiorella 2022). The *personalization principle* suggests that personalizing instructors in multimedia environments increases social agency between the instructor and student, which enhances learning (Lawson et al. 2021). Last, the *generative activity principle* suggests completing strategies when learning in multimedia environments helps students to actively process the material, which enhances learning (Fiorella et al. 2020). When these design

principles are enacted, they aid student learning, freeing mental resources that can then be allocated to the processes and skills necessary for students to self-regulate their learning, including monitoring and control of their motivation, affect, and adaptive strategy use.

The Multimedia Principle

The multimedia principle helps students iteratively monitor the relevance of verbal and visual content while *selecting* and *organizing* it to construct their mental model. Students use the goals they set for their learning to determine what information in each modality is important for achieving their goal, while filtering out irrelevant information. Each modality facilitates selection of information from the other because the learner does not have to use their limited cognitive resources towards maintaining either the verbal or visual information in their memory and can, instead, consult the learning materials to continue their search and selection process (Strobel et al. 2018).

Next, students *organize* the relevant information into a mental model and make metacognitive judgments about whether their constructed mental model is sufficient for the goal to be achieved (Azevedo & Dever 2021). During learning, students can lean on visual information in the learning materials to make metacognitive judgements about the differences and similarities between those external models and their internal mental models. Visual information facilitates this process because it is presented by salient external models that represent how concepts are organized relationally. Thus, students do not need to maintain that information in memory and can offload some of their cognitive processing onto external models (Kuhlmann & Fiorella 2022). Then, students can use the remainder of their cognitive resources to locate inconsistencies between external and internal models, and correct those errors (Van Meter & Firetto 2013). Prior research has established that students frequently monitor their

learning when playing a serious computer game and those instances of self-monitoring were positively related to higher quality mental models (Riemer & Schrader 2019).

The Personalization Principle

The personalization principle suggests personalizing computer-based instructors with conversational language, appealing voices, and human-like gestures increases social agency between the instructor and student, which, in turn, fosters a sense of belonging and positive affect that motivates students to engage in SOI processes that foster learning (Lawson & Mayer 2007). For example, researchers have found that students who were taught by a computer-based instructor who conveyed positive messaging through their voice and body movements found the instructor more credible and engaging than students who learned from frustrated or bored instructors. These students were also more cognitively engaged and learned best from the multimedia CBLE (Lawson et al. 2021). However, this research does not capture how students iteratively regulate their affect, motivation, or other SRL skills during learning (Ben Eliyahu 2019). Instructors can personalize multimedia CBLEs to facilitate SRL by modeling self-regulated learning skills parallel to teaching domain-specific content. For example, within hypermedia environments, SRL is taught through adaptive scaffolding, in which students' understanding of the system is used to provide individualized support regarding how they should sustain or update their learning (Azevedo et al. 2007). This scaffolding can fade over time to allow students to develop and enact more agency in regulating their learning within the CBLE.

Personalizing content within multimedia CBLEs to individual student needs and interests also supports their SRL. Students' prior knowledge is an essential individual student characteristic through which CBLEs should be personalized. Cognitive tutors use problem-solving tasks to determine students' prior knowledge within a domain and then engage students

in adaptive problem-solving to achieve mastery (Koedinger & Corbett 2006). This personalized design facilitates problem-solving because the cognitive tutor uses actual data on students' problem-solving history to inform a model of a student's knowledge. Also, since students start learning at an appropriate level of difficulty, they are more likely to maintain a balance between their positive affect and effortful learning during problem-solving, rather than becoming frustrated during learning (Riemer & Schrader 2019). Multimedia CBLEs can also be personalized to students' interests, which prior research has shown increased students' enjoyment of and value for what they were learning, and supported their achievement (Bernacki & Walkington 2018).

The Generative Activity Principle

Students learn best from multimedia CBLEs that require them to engage in generative activity, such as completing adjunct strategies. Several strategies support the generative cognitive processes necessary for learning (in other words, selecting, organizing, integrating), including drawing and teaching (Fiorella & Mayer 2016). These strategies also support students' SRL when incorporated into multimedia CBLEs. It is challenging to fully understand students' SRL processing because these processes are mostly internal; however, drawing and teaching are two exemplary strategies that require overt SRL skills and behaviors that better allow researchers to measure and understand how students self-regulate their learning (Cleary et al. 2015).

In learner-generated drawings, students translate content from a multimedia lesson into their own visual by drawing with paper, pencil, or computer tools (Fiorella & Mayer 2016). Drawing facilitates SRL because it is a goal-directed activity that helps students organize their knowledge and acts as an external scaffold for them to monitor and evaluate their progress toward their goals (Van Meter & Firetto 2013). Imagine a student learning about the human

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nervous system through a lecture video in their psychology course. Before starting the video, the student set a goal to understand the connections between the peripheral and central nervous systems. However, they realize while watching the video that the content is moving quickly, and they are struggling to maintain the information in their memory. So, the student pauses the video and draws their own visual of the material. They use the goal of understanding connections between the peripheral and central systems to start drawing (*selecting*) and continue using that standard to metacognitively monitor how they execute the strategy (*organizing*). Completing their drawing to a set standard is a propelling force for self-monitoring because successful enactment of the strategy is likely blocked if the student struggles to generate a portion of their drawing. This struggle indicates the student has a misunderstanding about how the remainder of the content should be generated in the drawing or how prior content has been portrayed in the drawing. Then, they must use self-monitoring to locate and update those inconsistencies in their mental model (*integrating*).

Learning by teaching involves explaining multimedia material with the goal of helping others learn. Learning by teaching can involve just preparing to teach to others or preparing and actually explaining to others (Fiorella & Mayer 2014). Teaching is a strategy that uniquely supports SRL because it requires students to plan out learning for themselves and for others. This planning phase is highly elaborative because students must think about the standard at which they want others to understand their explanation, *select* content from multimedia materials, and *organize* it in a way that will best support others' understanding. Then, when teaching, students must frequently monitor their explanations for accuracy and clarity to ensure they are explaining the material in a way that others can understand. While self-monitoring their explanations, students are likely to find instances in which a concept could be explained differently and will

then need to adapt their explanation accordingly. There are also multiple opportunities for instructors to incorporate learning by teaching into CBLEs, such as by teaching a pedagogical agent (Fiorella et al. 2019) or to fictitious peers on camera (Hoogerheide et al. 2014).

-Insert Table 1 Here-

Conclusion

How students self-regulate their learning in multimedia CBLEs informs how they will learn from such environments, and enacting multimedia design principles further facilitates cognitive and SRL processes that foster learning from such environments. Students who can cognitively process the learning material generatively and effectively self-regulate their learning in CBLEs are more likely to be successful when learning in these environments; however, effectively doing so is challenging for students. Instructors can support students in these efforts by designing CBLEs according to the multimedia, personalization, and generative activity principles. Instructors can design verbal and visual representations in multimedia CBLEs such that students can easily integrate them into a coherent external model, allowing them to lean on those external models to support their metacognitive sense-making processes. These environments can also be personalized to support one or multiple student needs by modeling SRL skills and tailoring content to students' interests. Instructors can also engage students in generative activities when learning with CBLEs. Students can concept map and self-test with computer tools directly within the environment or students can use traditional paper and pencils to draw about what they are learning outside the CBLE. Students can also lean on themselves to self-explain or mentally imagine the material, or they can lean on their peers to engage in a teaching activity. Instructors, instructional designers, and researchers working with CBLEs in higher education would do well

to consider how students self-regulate their learning in such environments and how multimedia designs further facilitate students' self-regulated learning processes and skills.

Pre-Publication Version

Table 1.

Examples of how each design principle can be used to foster cognitive and SRL processes in multimedia CBLEs.

Design Principle	Cognitive Process	SRL Process	Examples
Multimedia	Selection	Setting Goals	<i>Students use their goals to select relevant information from the environment.</i>
		Strategy Enactment	<i>Students use visual information as an external model to monitor the accuracy of their mental models and go back to the environment to select missed information.</i>
	Organization	Setting Goals	<i>Students monitor whether their mental model is on target with their goals.</i>
	Organization/ Integration	Strategy Enactment	<i>Students use information in the environment as an external model to metacognitively monitor the accuracy of their mental models and integrate their mental models with their prior knowledge.</i>
		Evaluation	<i>Students evaluate the accuracy of their mental model, test that model for inaccuracies, and refer to the environment to update their understanding.</i>
Personalization	Organization/ Integration	Strategy Enactment	<i>Instructors that foster social agency help students to minimize and regulate negative affect, which motivates them to sustain meaningful processing as they construct and update their mental models.</i>
	Selection	Defining the Task/ Setting Goals	<i>Personalizing content to students' prior knowledge and interests ensures they define the task and set goals at the appropriate skill level, which fosters their motivation to select relevant information from the environment.</i>
Generative Activity	Integration	Evaluation	<i>Students use generative drawings as an external model to evaluate the accuracy at which they have integrated new and prior knowledge into a mental model.</i>
	Selection/ Organization	Setting Goals	<i>Students set a standard for which they want others to understand their explanations when teaching and use those standards to select and organize relevant information.</i>

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