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Applying learning theories and instructional design models for effective instruction

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Khalil MK, Elkhider IA. Applying learning theories and instructional design models for effective instruction. *Adv Physiol Educ* 40: 147–156, 2016; doi:10.1152/advan.00138.2015.—Faculty members in higher education are involved in many instructional design activities without formal training in learning theories and the science of instruction. Learning theories provide the foundation for the selection of instructional strategies and allow for reliable prediction of their effectiveness. To achieve effective learning outcomes, the science of instruction and instructional design models are used to guide the development of instructional design strategies that elicit appropriate cognitive processes. Here, the major learning theories are discussed and selected examples of instructional design models are explained. The main objective of this article is to present the science of learning and instruction as theoretical evidence for the design and delivery of instructional materials. In addition, this article provides a practical framework for implementing those theories in the classroom and laboratory.

science of instruction; learning theories; instructional design; instructional design models

ALMOST ALL FACULTY MEMBERS who teach in higher education as subject matter experts lack formal training in the science of instruction and instructional design, even though they routinely design instructional materials. That is, faculty members are involved in instructional design activities that mostly lack scientific underpinning and proper documentation (13, 25). In contrast to subject matter experts, instructional designers are formally trained to use several instructional design models that have been developed for systematic planning and the development of instruction. These systematic processes in designing instruction are aimed at increasing instructional efficiency and facilitating student learning. In that respect, design models translate the general principles of learning and instruction to provide a procedural framework for developing instructional materials and creating an environment for successful learning outcomes.

Although there are many different design models available, all of them include the following essential phases of instructional design: analysis, design, development, implementation, and evaluation phases. The designer's main task is to perform instructional analysis to determine instructional goals, develop instructional strategies, and develop and conduct an evaluation to assess and revise instructional materials. Like instructional designers, faculty members also use aspects of instructional design. They consider the program objectives to identify their session objectives, develop learning activities to reach these objectives, and assess learners' progress toward achieving those objectives. However, faculty activities in planning educational experiences or designing educational investigation should be guided and supported by the science of learning and instruction.

The main objectives of this article are to present the theoretical evidence for the design and delivery of instructional materials and to provide a practical framework for implementing those theories in the classroom and laboratory. Three sections are included to present the science of learning and related learning theories, the science of instruction, and a framework for implementation.

The Science of Learning and Related Learning Theories

How do people learn?. The information processing model (Fig. 1) is the prevailing theory in cognitive psychology. It includes three types of memory (sensory, working, and long-term memory) that interact to encode incoming information. All information perceived by sensory memory will pass to working memory when the learner pays attention to it. To be learned, materials must be processed in working memory, which reflects our consciousness, where mental activities take place. Working memory is very limited in duration and capacity (1, 32). The limitation in working memory is considered a critical factor when designing instruction (34, 41, 42).

Students use two types of rehearsal when processing information in the working memory: maintenance and elaborative rehearsal. Maintenance rehearsal, or rote memorization, occurs when the learner goes over the learning material many times to remember it without thinking (surface learning), whereas elaborative rehearsal is the process of organizing the information to reach meaning (i.e., understanding or deep learning). The process of rote memorization is more passive and leads only to short-term retention, whereas elaborative rehearsal is an active learning process that is useful for transferring the information into long-term memory. Unlike working memory, long-term memory is unlimited in capacity and stores information permanently in forms of organized schemas. Therefore, the goal of instructional delivery is to encourage understanding over rote memorization and to facilitate the process of elaboration for better encoding of content to be learned. Strategies to promote understanding or deep learning are not limited to instructional delivery but are also linked to assessment strategies.

Domains of learning. Gagné (9) identified the five domains of learning that affect the learning process: *1*) motor skills, *2*) verbal information, *3*) intellectual skills, *4*) cognitive strategies, and *5*) attitudes. Motor skills require repetitive practice to master and include such examples as taking a pulse, the introduction of a nasal tube, and performing dissection in the laboratory. Verbal information refers to the factual knowledge and principles in the curriculum, and their learning requires organized presentation and meaningful context. Intellectual

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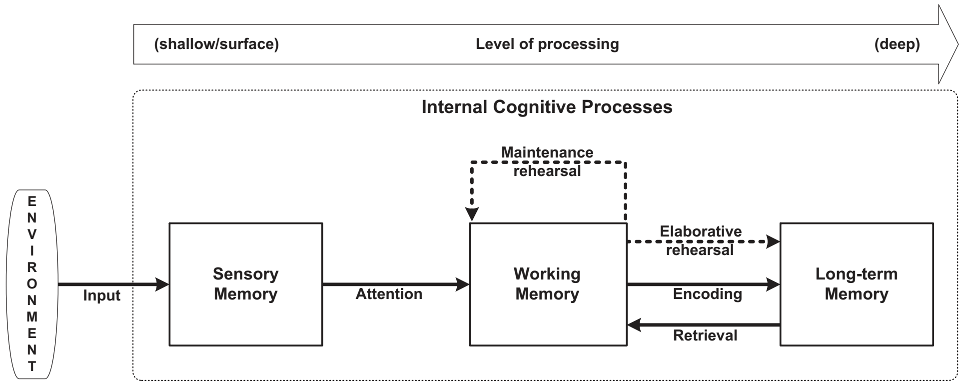

Fig. 1. Relationship between the types of memories and types of rehearsal for encoding information. Also shown is the level of processing from surface (maintenance rehearsal) to deep (elaborative rehearsal) in encoding incoming information.

skills are the elaboration of basic concepts and rules, the learning of which is based on prior assimilation of prerequisite skills. The subcategories of intellectual skills are discrimination (e.g., distinguish between an isometric and isotonic contraction), concrete concepts (e.g., identify the differences between the cerebrospinal fluid and plasma), defined concepts (e.g., classifying the different groups of sensory nerve fibers), rule learning (e.g., calculating the pulse pressure and mean arterial pressure), and higher order rules (e.g., problem solving). A simple example to illustrate the difference between verbal information and intellectual skills is that to recall the definition of creatinine clearance is verbal information; however, using the Cockcroft-Gault equation to estimate creatinine clearance to assess the function of the kidneys is an intellectual skill.

Cognitive strategies are internally organized skills that control learning behaviors, remembering, and thinking, which are learned by practice. Learners develop these strategies by reflecting on their own experiences or they may be taught effective learning strategies. Attitudes are considered to be in the affective domain and are not learned by practice. Changing attitudes requires human modeling with reinforcement and feedback. Attitudes affect a student's motivation to learn. For example, a student with a positive attitude and interest in physiology will regularly attend physiology classes.

The main message in recognizing the different domains of learning is that different instructional concepts require the selection of different instructional strategies and different methods of assessment. The selection of only one teaching method to deliver all physiology sessions in the curriculum introduces unnecessary limitations that might negatively affect the learning outcomes.

Learning theories. Ertmer and Newby (6, 8) nicely explained the importance of linking instructional strategies or techniques to the theories of human learning. They indicated that learning theories are considered a source of verifying instructional strategies as well as a foundation for the selection of specific strategies. The theories provide information about the relationships among strategies, context, and learner characteristics for better integration, and, most importantly, learning theories allow for reliable prediction of the effectiveness of the selected instructional strategies.

Behaviorism, cognitivism, and constructivism are the three primary learning theories (6, 8, 43). The general characteristics of these theories are shown in Table 1. The three theories differ in how learning is defined, which subsequently leads to different roles for the learners, and dictates that different teaching methods and assessment strategies are used.

In addition to the above-mentioned primary learning theories, we discuss below the basics of adult learning theory, cognitive load theory, and multimedia theory as important theories affecting the way we design instruction to accommodate the learners' characteristics and experience.

Adult learning theory is defined by andragogy and self-directed learning principles (20, 30). Andragogy is the art and science of helping adults learn (19, 21), and self-directed learning is a process in which the locus of control in learning lies with the adult learner (20, 30). A primary principle of adult learning theory is that when designing instruction one should capitalize on the learner's experience (e.g., entry behavior). Adult learners are independent in directing their own learning, have accumulated rich life experience, have set professional and personal goals, are internally motivated, are problem centered, and seek the relevance of the new knowledge. The

Table 1. *The three primary learning theories*

	Behaviorism	Cognitivism	Constructivism
Definition of learning	Learning is the acquisition of new behavior	Learning involves the acquisition and reorganization of cognitive structures	Learning is search for meaning
Learner's role	Passive participants in the learning process	Active participants in the learning process	Active participants in the learning process
Main strategy	Facilitates knowing what	Facilitates knowing how	Reflection in action
Implication	• Objective-based instruction • Competency-based education • Skill development and training	• Concept maps • Reflective thinking	• Authentic case-based learning environment • Reflective practice • Collaborative construction of knowledge
Example of teaching method	• Lecture • Simulation • Demonstration • Programmed instruction	• Problem solving • Concept mapping • Advanced organizer	• Diaries/reflection • Role modeling • Problem-based learning • Collaborative learning
Assessment strategies	Criterion-referenced assessment: multiple-choice questions and recall items	Essays, written reports, and projects	Elimination of grades and standardized testing; peer grading/review

theory encourages learners to actively participate in the learning experience and directs selection of teaching methods that promote experiential learning. Information about entry behaviors, attitudes toward content and delivery method, academic motivation, general learning preferences, and group characteristics are very useful and influential in guiding the design of instruction.

Cognitive load theory (40, 42, 47) assumes that, for effective learning, the learner's cognitive architecture should be aligned with instructional conditions. The learner's cognitive architecture consists of sensory memory, working memory, and long-term memory. The theory assumes that learning occurs through very limited working memory and unlimited long-term memory. Working memory is limited in capacity and duration when dealing with novel information (1, 32). Working memory is composed of two processors for auditory and visual information, respectively, with central or executive control (2), which processes three types of cognitive load: intrinsic, extraneous, and germane load. The intrinsic cognitive load results from the number of interactive elements that the learner processes simultaneously in working memory (i.e., the intellectual complexity of the concepts or instructional materials). For example, the identification and description of the zonation of the adrenal cortex have low element interactivity, i.e., the name of the different zones and types of cells present in each zone. However, the biosynthetic pathway for glucocorticoids, mineralocorticoids, and androgen is more complex due to the interaction of many elements for the biosynthesis of these adrenocortical hormones. Extraneous cognitive load is generated by suboptimal faulty presentation of instructional materials. The addition of textual explanations describing positive and negative feedback to a self-contained diagram of the hormonal feedback mechanism that uses obvious plus and minus signs is considered redundant information that imposes unnecessary cognitive load. Germane cognitive load results from learner interactions with the appropriate instructional design that contributes to learning. The general principle using cognitive load theory is to reduce extraneous cognitive load, manage intrinsic cognitive load, and promote germane load. It is very important to consider the cognitive load imposed by instructional design due to the limitation of working memory. Otherwise, instruction becomes inadequate because it imposes high extraneous cognitive load irrelevant for learning (42). For example, when using animations to explain organ function, it is better to provide the learner with auditory explanations rather than on-screen written explanations. It is effective to use dual-mode presentation instead of overloading the visual processor in the working memory. The design principles and strategies stemming from cognitive load theory are highly relevant when teaching complex physiological concepts. Many examples of design guidelines based on cognitive load theory have been offered to decrease extraneous load, manage intrinsic load, and optimize germane load (e.g., Refs. 24, 48, and 50).

Multimedia theory, or learning from words (verbal) and pictures (pictorial), is based on the researched-based cognitive theory of multimedia learning (27, 28). The theory is grounded on three principles: the dual-channel principle, limited capacity principle, and active processing principle. The dual-channel principle indicates that there are two separate channels for processing verbal and pictorial information in working memory (35). The limited capacity principle (1, 32) deals with the limitation of working memory to simultaneously process several pieces of information. The active processing principle indicates that, for meaningful learning to occur, the processing of new selected and organized information in working memory requires activation and integration with prior knowledge stored in long-term memory (49). The goal of multimedia theory and cognitive load theory is to use evidenced-based principles for instructional design that reduce extraneous cognitive processing and help to manage the amount of information presented to learner to avoid overloading the learner's cognitive capacity (28, 33, 41, 42). The work of Issa and colleagues (12, 13) presented evidence that applying multimedia design principles to modify PowerPoint (PPT) slides in medical education improved short-term retention, long-term retention, and knowledge transfer among medical students. An example of reducing extraneous cognitive load during PPT presentation is to minimize text on the slide, especially if instructors intend to discuss an image or a diagram. As indicated by the dual coding principle, working memory has two partially independent processors for visual and auditory information. It is better to share the cognitive load between the two processors rather than overload the visual processor. In addition, too much text on a PPT slide results in split attention between reading the textual information and listening to the instructor.

The Science of Instruction

Based on an understanding of how people learn, the science of instruction is concerned with the rational development of instructional design strategies. Effective design of instructional materials elicits appropriate cognitive processes in the learner and mediates more successful learning outcomes.

The principle of instruction. Five principles of instruction have been identified (31) that promote learning: *1*) learners are engaged in solving real-world problems, *2*) existing knowledge is activated as a foundation for new knowledge, *3*) new knowledge is demonstrated to the learner, *4*) new knowledge is applied by the learner, and *5*) new knowledge is integrated into the learner's world.

These principles can be implemented using different delivery/teaching methods to create effective learning environments. The first principle emphasizes problem-centered instruction or involving students in real-world tasks. For effective instruction, problems should be relevant, interesting, and engaging (14), and there should be a progression from less complex to more complex problems (36, 44). In the second phase of activating previous knowledge, prior mental models or schema are activated to promote instructional effectiveness. Simply put, to avoid overwhelming students who lack foundational knowledge, provide them with relevant experience to be used as a foundation for the new knowledge (17). This step is often ignored by faculty members who assume all students have similar educational backgrounds, although admission committees try to diversify the student body by accepting qualified students of different backgrounds. In the third demonstration principle, information is presented to the learners. In this phase, we'll discuss basic educational theories for effective instructional strategies and give examples of instructional design models that could be used to guide the design and development of instructional materials. The fourth phase is to apply learned knowledge in different authentic situations and to provide feedback for guidance. For example, in a medical school setting to teach basic sciences including physiology, it is important to provide the clinical relevance for the basic science information and explain important relationships. Thereafter, provide students with different clinical scenarios to apply what they have learned to solve clinical problems. The last phase, integration or the transfer of knowledge, is used in different ways.

Instructional design models. Although there are many instructional design models, here only the analysis, design, development, implementation, and evaluation (ADDIE) model (10), Dick and Carey model (5), and the 4CD/ID model (45, 46) are discussed. Both the ADDIE and Dick and Carey models use a behavioral approach in designing instruction. However, the ADDIE model is simpler and easier to use than the Dick and Carey model, which elaborates on instructional design phases. The 4C/ID model is aligned with cognitivists learning approaches and is informed by cognitive load theory in designing instruction for learning complex tasks.

To produce effective instruction, all instructional design models require the following phases: analysis, design, development, implementation, and evaluation. These instructional design phases are summarized by the acronym ADDIE, and hence it is now considered a separate model. The ADDIE model (Fig. 2) provides systematic approach for designing and developing a learning experience. The outcome of each ADDIE phase informs the subsequent phase.

In the analysis phase, the learner, context, and instructional materials are analyzed to identify the characteristics of the target learner (e.g., existing knowledge, previous experience, interests, and attitudes) and determine instructional goals and the learning context/environment. In the design phase, the learning objectives are identified to outline content and instructional strategies. The latter consists of preinstructional activities, content presentation, and learner participation. During the design phase, the delivery methods, types of learning activities, and different types of media are selected. The development phase includes creating the instructional contents, a prototype, and assessment instruments. The implementation phase is the actual delivery of instructional materials to support students' mastery of the learning objectives. The evaluation phase includes formative and summative evaluation. The formative evaluation occurs between the phases throughout the entire instructional design process to continuously improve instruction before final implementation. The summative evaluation occurs after the implementation of the final version to assess the overall effectiveness of instruction.

Dick and Carey (5) outlined the importance of using a systematic approach in designing instruction. The components of the system include the teacher, learner, instructional materials, and learning environment. The effectiveness of the systematic approach in designing instruction is to provide *1*) focus when a clear goal or objectives are stated up front to guide the design of instruction, *2*) careful linkage between each component, and *3*) an empirical and replicable process. The Dick and Carey model includes the following steps:

- Identify instructional goals
- Conduct instructional analysis
- Identify entry behaviors and learner characteristics
- Write performance objectives
- Develop criterion-referenced test items
- Develop instructional strategy
- Develop and select instructional materials
- Develop and conduct formative evaluation
- Develop and conduct summative evaluation

The Dick and Carey model provides detailed step-by-step processes that could easily be followed. It is very helpful for novice instructional designers to understand the details regarding the principles of the systemic approach to instructional design. The main difference between the Dick and Carey model and ADDIE model is that the former includes all the essential phases described in the ADDIE model but with more elaboration. An example of this elaboration is what happens in the analysis phase, which facilitates the writing of performance objectives or learning outcomes (i.e., what a learner should be able to do; Fig. 3). The analysis is guided by assessing the needs to identify the gap followed by writing the instructional goals and then the performance objectives. Analyses of instruction, learners, and context are outlined as the necessary processes in identifying the goals and writing performance objectives, and the focus of the analyses outcomes are also defined.

The 4C/ID model (45, 46) mainly deals with complex learning and has four components. The model outlines the need for authentic learning processes, managing cognitive load dur-

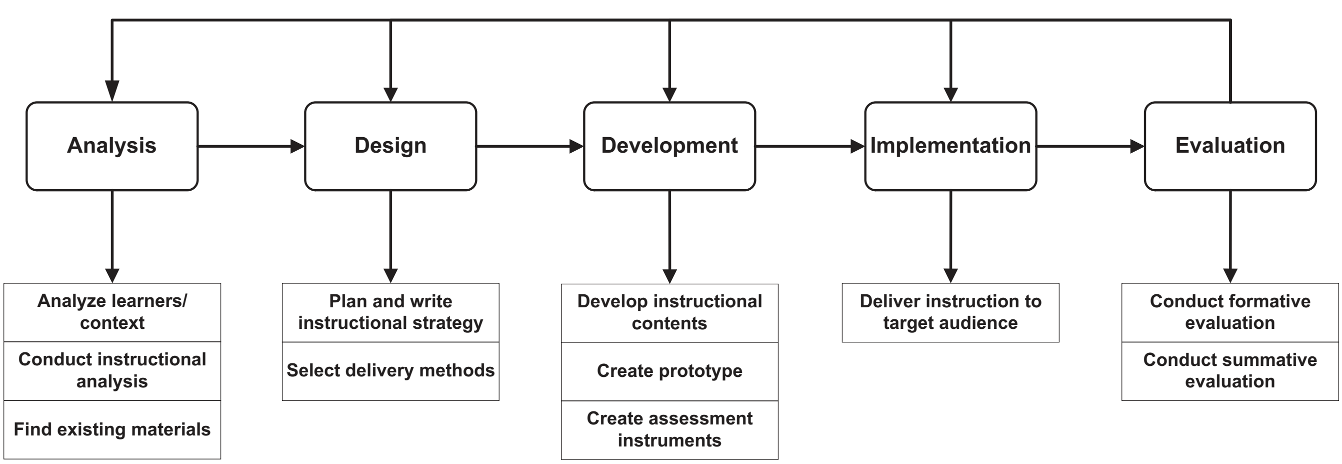

Fig. 2. Analysis, design, development, implementation, and evaluation (ADDIE) model phases and the steps during each phase.

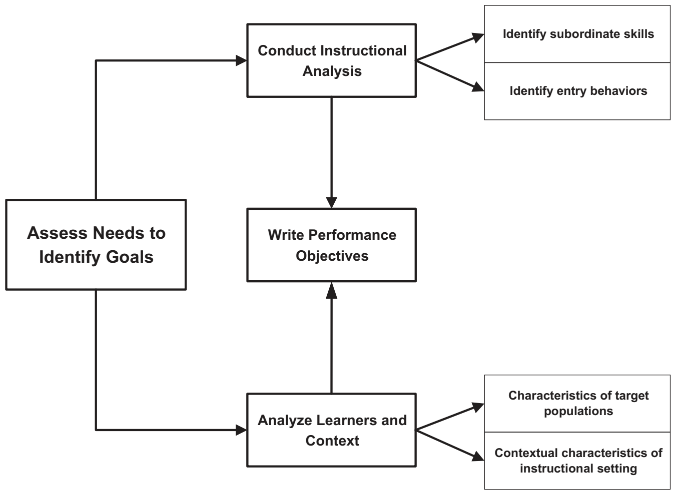

Fig. 3. Steps in Dick and Carey model during the analysis phase to write the performance objectives.

ing learning, repeated practice, and assessment and feedback. It is an excellent model for integrating complex concepts from different disciplines. The model suggests ordering learning tasks from low to high cognitive activities, focusing the learner's attention onto the most challenging aspect of learning, and promoting germane load when scaffolding the learner's efforts as he or she interacts with simple to complex tasks. The learning environment in the 4D/ID model is divided into the following four components:

- Learning tasks that are concrete and authentic whole-task experiences. The tasks are organized from simple to complex activities, and a high level of support is provided to the learner at the beginning, which later diminishes by the end of the task (scaffolding).
- Supportive information provides a bridge between the learner's prior knowledge and learning tasks. It consists of mental models, cognitive strategies, and cognitive feedback.
- Just-in-time information is prerequisite information to the learning and performance, which consists of demonstrations and corrective feedback. The information is presented when needed and fades with acquiring expertise.
- Part-task practice provides learners with additional practice for selected aspects of the whole task to ensure the achievement of desired learning outcomes.

In organizing the tasks into simple to complex activities and providing supporting information, it is very important to consider the learner level of expertise and background, especially because a diverse student body is now recommended for admission to many schools. For example, many students accepted into medical schools are from rural, economically disadvantage areas and are ethnic minorities. In addition, it is very common to have students with biological sciences, engineering, and social sciences backgrounds in the same class. To overcome this issue, development of online learning activities would be provided before class to meet the needs of those students [i.e., self-learning modules (17)] or enrolling students in prematriculation enrichment courses. Once again, this would emphasize the importance of conducting learner analysis as part of the analysis phase.

The unique aspect of the 4C/ID model is that it is used in planning training for complex learning. Developing learning experiences to teach physiology could be guided by the simple ADDIE model. However, the 4CD/ID model is appropriate for creating learning activities for teaching complex physiological concepts or complex courses. For example, the 4CD/ID model has been used for designing a course on communication skills (39) and in designing training for evidence-based medicine skills in the classroom and clinical settings (26).

From the above-listed examples of instructional design models, the ADDIE model (Fig. 2) is the most popular model used for designing instruction. It is easy to follow and provides a simple structure. Physiologists of different instructional design experience can use the ADDIE model to guide the development of their instructions.

Framework for Implementation

The above-mentioned theories and instructional design models have very practical implications for how faculty members design instruction and deliver content in the classroom and laboratory. The ADDIE model provides a simple and easy-to-use framework for designing instruction. If there is a need for more information and detailed explanations of what happens in each phase, the Dick and Carey model will be helpful. However, if you are dealing with very complex materials, then the 4CD/ID model is your best choice. General examples of what to do in all the essential instructional design phases are provided below.

Analysis phase. Often faculty members think as subject matter experts and assume that, if they know the content, they know what works and what doesn't with regard to teaching that content. However, students come to class with misconceptions or lacking the required entry behaviors. Even students who may have met the prerequisites may not demonstrate adequate understanding of the foundational knowledge and may not be able to connect it to the content at hand. This might surprise some faculty members, who assume all of their learners have mastered the prerequisite knowledge. To avoid such false assumptions, it's very important for faculty members to conduct instructional and learner analysis to identify subordinate skills, entry behaviors, and characteristics of the target learners, that is, to know what students might know and what they might not know before they arrive to the class or laboratory. This step will help faculty members determine the objectives and plays a major role in choosing the instructional strategies later on. Without proper analysis, or only with the benefit of hindsight, faculty members teaching physiology may not know which concepts are more challenging for learners and need more emphasis and which concepts are likely to be most easy for learners and thus can be glossed over. In this analysis phase, and especially in higher education and professional schools, it is important to consider the principles of adult learning theory, which describe many parameters of adult learners that inform the design of instruction for successful learning outcomes.

Design phase. When faculty members start to think as instructional designers, they will be able to deal with learning as a process, not as a set of content areas. A crucial part of the learning process is creating specific and detailed learning objectives so that not only will the learners know what is

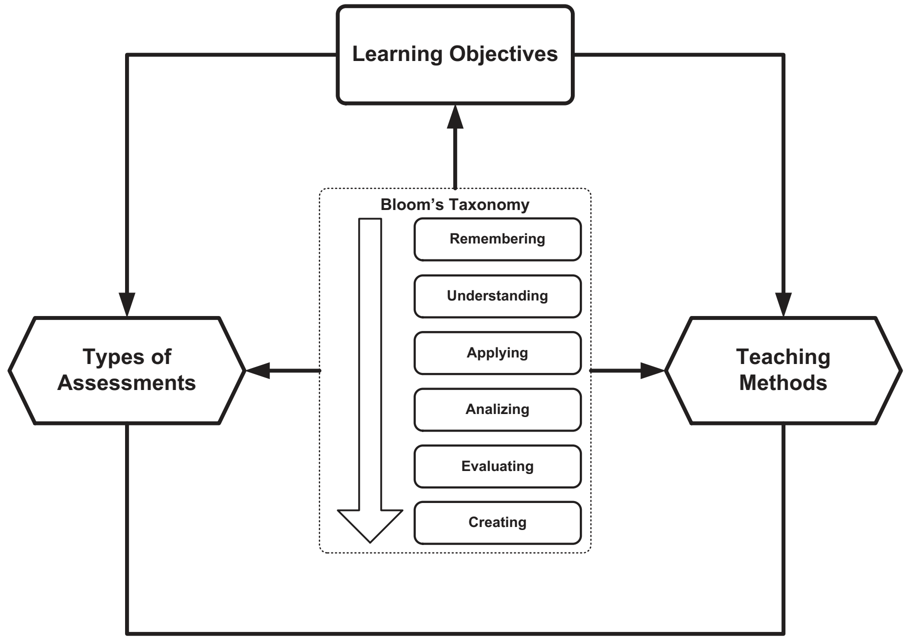

Fig. 4. Utilization of Bloom's taxonomy cognitive level in writing learning objectives and how these objectives are related to the selection of teaching methods and assessment strategies.

expected of them and what is important but the faculty members can determine how they will teach the content as well as how they will evaluate and assess the instruction and the learners' success. Therefore, this design phase should be systematic and specific. To create useful learning objectives, use measurable verbs ("define," "explain," and/or "list") and avoid nonbehavioral verbs ("understand," "know," and/or "grasp"). Consider the beginning level of your learner's knowledge and skills and choose objectives to move them to the next level.

Based on the learning objectives, faculty members need to select the appropriate teaching methods for the cognitive level of the learning objectives and decide which type of assessments should be used to monitor the learner's progress and success (Fig. 4). For example, it is advisable to develop assessment instruments that are parallel to the stated learning objectives with an emphasis on relating the domain of learning and cognitive level of the objective to what the assessment requires. For example, referring to Gagné's domain of learning, a motor skill is usually assessed using a checklist as to the presence or absence of the skill and attitude is assessed by a rating scale as to degree. Low cognitive level verbal information (remembering, understanding, and/or applying) could be assessed by simple identification of an anatomic structure in a laboratory setting, whereas high mental cognitive intellectual skills (analyzing, evaluating, and/or creating) could be assessed with problem sets, data analysis, or student presentations.

Table 2. *Comparison between formative and summative assessments*

	Formative Assessment: Assessment for Learning (Support of Learning)	Summative Assessment: Assessment of Learning (Validation and Certification)
Definition	Encompassing all those activities undertaken by teachers and/or by their students that provide information to be used as feedback to modify the teaching and learning activities in which they are engaged (3)	"The process of assessment leads to summative assessment, that is, a judgment which encapsulates all the evidence up to a given point. This point is seen as a finality at the point of the judgment." (42a)
Function	• Guiding future learning • Helping students assess their own learning progress • Encouraging self-regulated learning and active learning strategies • Promoting self-assessment and deeper approach to learning • Promoting reflection and developing self-evaluation skills • Maintaining motivation and self-esteem	• Making judgment • Creating hierarchies of selection
Characteristics	• Promotes learning as part of teaching • Takes into account the progress of each individual learner • Provides diagnostic information for appropriate interventions • Requires learners to be active in their own learning	• Takes place at certain intervals in reporting achievement • Reports combined assessment for all learners • Requires reliable and valid methods • Based on evidence from the full range of performance relevant to the assessment criteria

Similarly, for different domains of learning, the appropriate teaching methods are required. Active lecture and self-directed computer-based instruction are more appropriate for teaching low cognitive level objectives, whereas problem-based learning, discussions, or case studies are appropriate methods for teaching high cognitive level objectives.

Development phase. After completing the design phase, faculty members are now ready to create and develop content that is targeted to the learners and desired level of learning. In the development phase, faculty members design the structure and flow of the information as well as the type of media that will be used to deliver the content and develop the learning activities. Faculty members can modify existing resource materials to align with the goal of the learning activities or can develop new materials. It is worth the effort to update previous year PPT presentations and other learning materials based on the current learners' analysis and design decisions. In this phase, it is important to refer to the principles of multimedia design (27, 28) and cognitive load theory guidelines (24, 48, 50) to create your instructional materials. Faculty members could simply apply these principles in creating their PPT slides, which has been reported to improve long-term retention and transfer (12).

Implementation phase. The implementation phase is the actual use of the learning experience. In this phase, learners are prepared and instructional context and technology are secured. Faculty members verify that learners have acquired the proper prerequisites and received orientation and training on the hardware and software to be used during the delivery of instruction and that they have access to all supporting materials. Faculty members also need to check the classroom/laboratory layout, equipment, and technology. For example, if you plan to use team-based learning, it is important to evaluate the learning space/setting to see if it is conducive for this type of teaching strategy. The implementation phase provides an opportunity to evaluate what was planned during the design phase and to make sure everything perform as predicted.

Evaluation phase. The last major step in the process is the evaluation phase. Evaluation can happen at any stage of the instructional design process. Formative evaluation is conducted during the design and development phases to improve instruction and learning materials and to make sure they are aligned with the learning goal and objectives. Faculty members can try out newly developed instructional materials with a small group of students and record their performance and feedback. Student feedback on the clarity, accuracy, sequence,

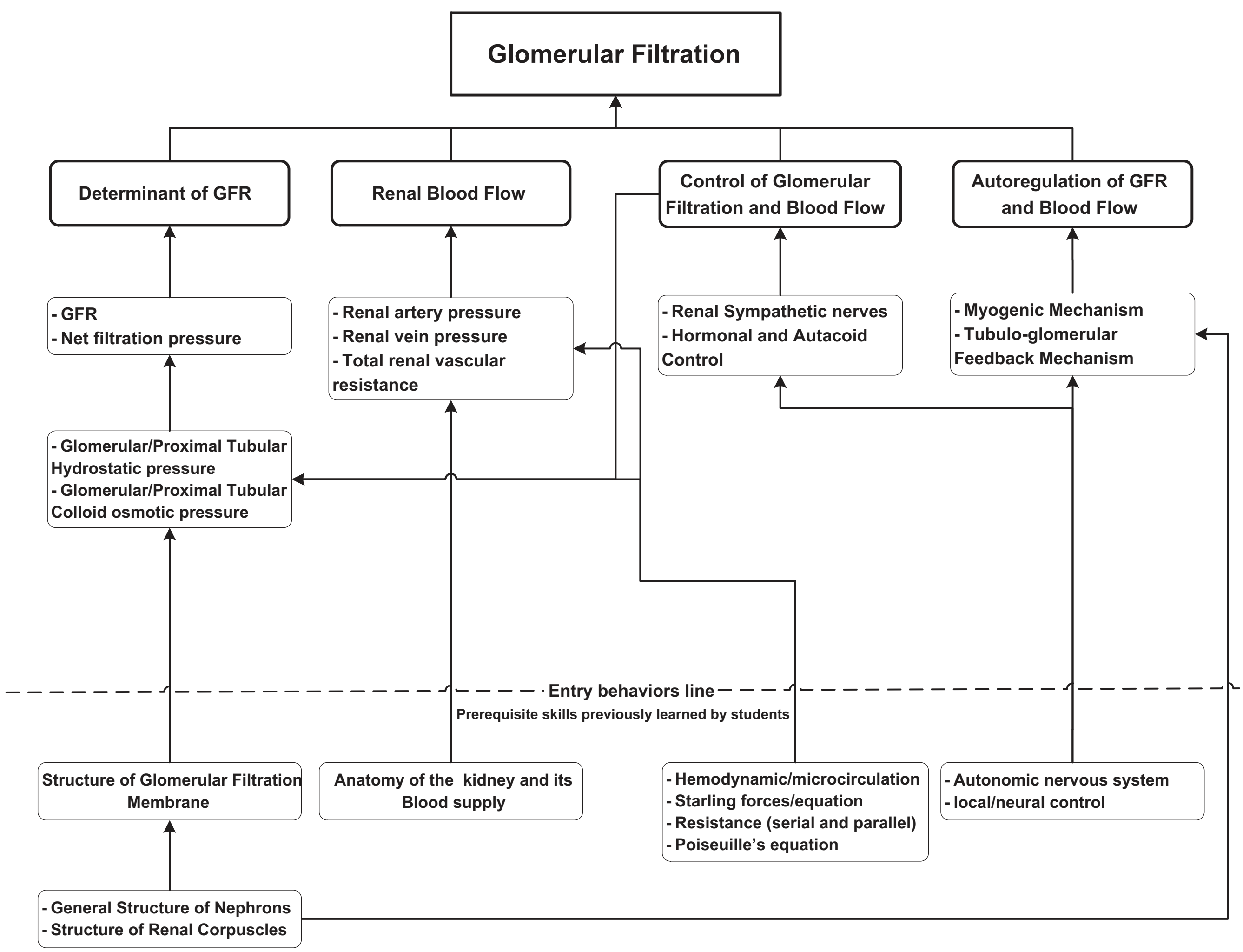

Fig. 5. Instructional analysis to teach the topic of glomerular filtration by identifying the main subtopics, subskills, and prerequisite skills.

and difficulty level will be corrected before the actual delivery of instruction to the entire class. A large-scale formative evaluation is usually conducted by the office of assessment and evaluation, which collects data on students' performance and perceptions toward specific courses or modules. Summative evaluation is conducted at the end of the instruction to ensure that learners achieved the learning objectives and that the course achieved its goals. It is important when assessing students' performance to clearly understand the difference between formative assessment, which is assessment for learning (3, 38), and summative assessment, which is assessment of learning (43). Table 2 shows a comparison between the two types of assessment and their definitions (3, 43), functions (50), and characteristics (11). Often, faculty members mistakenly turn formative assessment into summative assessment by assigning a score that is counted toward the final grade. Remember: with formative assessment you're trying to help students develop self-evaluation skills rather than trying to make judgments of their learning. The central component of formative assessment is providing feedback (37). Many researchers have linked the performance in formative assessment to summative assessment outcomes (18, 29) and the importance of self-regulation in developing skills for lifelong learning (7, 51, 52). The global appreciation of the value of formative assessment for learning is represented, for example, by the Liaison Committee on Medical Education requirement for provision of formative assessment in undergraduate medical education (23).

Evaluation is not limited to the evaluation of the student performance or their transfer of knowledge; it could also include evaluation of students' attitudes and motivation and evaluating the efficiency of instruction. To formally evaluate your session or course, keeps a notebook of your observations and elicit formal and informal feedback from students to make adjustments as necessary.

Example of Designing Student-Centered Learning Using Instructional Design Models

In this example, we will use the principles of instructional design for developing flipped classroom activities as an example of student-centered learning.

First, conduct instructional analysis of the course content or a session content to make sure it is appropriate for the flipped model. Figure 5 shows a simple example of an instructional analysis for a session intended to teach glomerular filtration and its application to glomerular diseases. This analysis identifies the main subtopics necessary for learning glomerular filtration as well as their required subskills and prerequisite skills (entry behaviors). The instructional analysis is usually followed by learners and context analyses to write the learning objectives for teaching glomerular filtration. Analysis of the learners is mainly conducted to identify if the learners have acquired the entry behavior skills or foundational knowledge (i.e., what and how much they know about the topic from previous experience). If the prerequisite skills of learning the structure of the glomerular filtration membrane are found to be a lacking knowledge during learner analysis, teaching these skills is required before the start of instruction. Lacking the adequate understanding of the foundational knowledge causes students to disengage and become frustrated in this type of learning.

Based on the learning objectives, faculty members should choose low cognitive level objectives for out-of-class learning (e.g., glomerular hydrostatic and colloid osmotic pressure), where students can self-learn the content at their own pace. In this case, classroom time will be spent learning high-level objectives (e.g., correlate laboratory findings of glomerular diseases to kidney function). To ensure that students master out-of-class learning materials, it is important to quiz students and review the materials at the beginning of the session before the application of the learned knowledge. Faculty members can select an instructional strategy for asynchronous web-based video lecture or individual computer-based instruction outside the classroom and interactive group learning activities inside the classroom to engage the learners and select the teaching modality that is appropriate for the cognitive level of the learning objectives. For example, as strategy for outside-the-classroom activities, lecture video is found to be better than textbook readings to prepare students for classroom activities (4). Examples of in-classroom teaching methods used with the flipped model are small group, team-based learning, problem-based learning, etc.

After the design step has been completed, faculty members now are ready to create and develop content for both the classroom and out of class that is targeted to the learners and desired level of learning. In the development phase, faculty members design the structure and flow of the information as well as the type of media that will be used to deliver the content and develop the out-of-class learning activities (short recorded videos, voice-over PPT slides, YouTube videos, etc.). Faculty members can use existing resource materials that are aligned

Table 3. *Checklist for designing a flipped classroom model*

Analysis
- Course content is appropriate for the flipped model
- Learners clearly understand the new model logistics (grades, participation, assessment, and technology)
- The learning space is conducive for the flipped model
- Course goal and objectives are clearly defined

Design
- Pedagogy-based teaching method is selected to interactively engage learners
- Content for out-of-class learning is selected based on the session objectives
- Assessment tools are selected to measure both in-class and out-of-class learning
- Classroom time is highly structured and planned

Develop
- Out-of-class content is developed based on instructional design principles
- In-class activities are directly relevant to the out-of-class work and force students to retrieve, apply, and extend the content learned
- Course offers multiple opportunities for students to learn the content and for the instructor to provide feedback on the learner's performance

Implement
- Course objectives and expectations on attendance and grades are clearly communicated
- Students clearly know where to find and when to submit course activities, assignments, and homework
- The instructional setting is conducive to learning
- Needed technology and equipment are available

Evaluate
- The course clearly assesses learning outcomes and learner's experience in the flipped classroom
- Summative and formative evaluation are conducted throughout the course delivery
- The instructor plans to use learners' feedback in an ongoing evaluation to improve the course

with the goal of learning activities, modify them to fit or develop new materials.

As part of the implementation process, clearly communicate to students the learning objectives, expectations, and grading policy. Students should also be prepared and have the skills to use the hardware and software used in delivering instruction. Ensure that learners have access to technology used to deliver out-of-class content and make sure the learning space, equipment, and technology are ready for the selected method of delivery.

The last major step in the process is the evaluation phase. Providing multiple opportunities for evaluation, both formative and summative, is very important to ensure the success of flipped classroom instruction. Online quizzes with the lecture recording make your lecture videos more interactive, and practice retrieval through answering questions significantly improves long-term retention (15, 16). An assessment after the out-of-class instruction is an excellent way to evaluate student comprehension of a topic and facilitate the use of mastery learning techniques (22). Based on out-of-class evaluation, faculty members can use classroom discussion or plan for just-in-time teaching at the beginning of class or laboratory to clarify any confusion. This is, if faculty members recognize that students lack subskills or prerequisite skills, it necessary to help students learn these skills before application exercises. Just-in-time teaching provides feedback between out-of-class and in-class activities to address any learning gaps. To summarize, Table 3 shows a checklist for designing flipped classroom activities.

Conclusions

In this article, we discussed the science of learning and instruction and related learning theories, with examples of instructional design models. The information presented makes it obvious that the planning of an educational experience is far from simply PPT presentations by subject matter experts conveying disciplinary knowledge to novice students. Omission of instructional design principles due to the lack of instructional design competencies leads to unanticipated and unexplained learning outcomes. Educational theory informs the design of instruction and instructional design models provide guiding framework for the development of effective, appealing, consistent, and reliable instruction. The effectiveness of the systematic approach in designing instruction provides an empirical and replicable process for reliable assessment to continuously and empirically improve the developed learning experience. Faculty members who are interested in advancing the education of their disciplines by conducting interventional pedagogical research must have developed competence and understanding of educational theories and the science of instruction.

DISCLOSURES

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AUTHOR CONTRIBUTIONS

Author contributions: M.K.K. and I.A.E. conception and design of research; M.K.K. prepared figures; M.K.K. and I.A.E. drafted manuscript; M.K.K. and I.A.E. edited and revised manuscript; M.K.K. and I.A.E. approved final version of manuscript.

REFERENCES

1. **Baddeley AD.** *Essentials of human memory*. Hove: Psychology Press, 1999.
2. **Baddeley AD, Hitch GJ.** Working memory. *Psychology Learn Motivat* 8: 47–89, 1974.
3. **Black P, Wiliam D.** Assessment and classroom learning. *Assess Educ* 5: 7–74, 1998.
4. **De Grazia JL, Falconer JL, Nicodemus G, Medlin W.** *Incorporating Screencasts Into Chemical Engineering Courses* (online). http://www.engr.uky.edu/~aseeched/papers/2012/5025.pdf [2 March 2016]
5. **Dick W, Carey L, Carey JO** (editors). *The Systematic Design of Instruction* (6th ed.). Boston, MA: Pearson/Allyn & Bacon, 2005.
6. **Ertmer PA, Newby TJ.** Behaviorism, cognitivism, constructivism: comparing critical features from an instructional design perspective. *Perform Improve Q* 26: 43–71, 2013.
7. **Ertmer PA, Newby TJ.** The expert learner: strategic, self-regulated, and reflective. *Instruct Sci* 24: 1–24, 1996.
8. **Ertmer PA, Newby TJ.** Behaviorism, cognitivism, constructivism: comparing critical features from an instructional design perspective. *Perform Improve Q* 6: 50–72, 1993.
9. **Gagne RM.** *The Conditions of Learning and Theory of Instruction*. New York: Holt, Rinehart, and Winston, 1985.
10. **Gustafson K, Branch R.** *What Is Instructional Design? Trends and Issues in Instructional Design and Technology*. Saddle River, NJ: Merrill/Prentice Hall, 2002.
11. **Harlen W, James M.** Assessment and learning: differences and relationships between formative and summative assessment. *Assess Educ* 4: 365–379, 1997.
12. **Issa N, Mayer RE, Schuller M, Wang E, Shapiro MB, DaRosa DA.** Teaching for understanding in medical classrooms using multimedia design principles. *Med Educ* 47: 388–396, 2013.
13. **Issa N, Schuller M, Santacaterina S, Shapiro M, Wang E, Mayer RE, DaRosa DA.** Applying multimedia design principles enhances learning in medical education. *Med Educ* 45: 818–826, 2011.
14. **Jonassen DH.** Designing constructivist learning environments. *Instruct Design Theories Models* 2: 215–239, 1999.
15. **Karpicke JD, Blunt JR.** Retrieval practice produces more learning than elaborative studying with concept mapping. *Science* 331: 772–775, 2011.
16. **Karpicke JD, Roediger HL, 3rd.** The critical importance of retrieval for learning. *Science* 319: 966–968, 2008.
17. **Khalil MK, Nelson LD, Kibble JD.** The use of self-learning modules to facilitate learning of basic science concepts in an integrated medical curriculum. *Anat Sci Educ* 3: 219–226, 2010.
18. **Kibble JD, Johnson TR, Khalil MK, Nelson LD, Riggs GH, Borrero JL, Payer AF.** Insights gained from the analysis of performance and participation in online formative assessment. *Teach Learn Med* 23: 125–129, 2011.
19. **Knowles MS** (editor). *Andragogy in Action: Applying Modern Principles of Adult Education*. San Francisco, CA: Jossey Bass, 1984.
20. **Knowles M.** *Self-directed learning: A guide for learners and teachers* New York: The Adult Education Company; 1975.
21. **Knowles M** (editor). *The Modern Practice of Adult Education: From Pedagogy to Andragogy*. Englewood Cliffs, NJ: Prentice Hall/Cambridge, 1980.
22. **Kulik CC, Kulik JA, Bangert-Drowns RL.** Effectiveness of mastery learning programs: a meta-analysis. *Rev Educ Res* 60: 265–299, 1990.
23. **Liason Committee on Medical Education**. *Functions and Structure of a Medical School. Standards for Accreditation of Medical Education Programs Leading to the M.D. Degree* (online). http://lcme.org/publications/ [2 March 2016].
24. **Leppink J, van den Heuvel A.** The evolution of cognitive load theory and its application to medical education. *Perspect Med Educ* 2015: 1–9, 2015.
25. **Levinson AJ.** Where is evidence-based instructional design in medical education curriculum development? *Med Educ* 44: 536–537, 2010.
26. **Maggio LA, Cate OT, Irby DM, O'Brien BC.** Designing evidence-based medicine training to optimize the transfer of skills from the classroom to clinical practice: applying the four component instructional design model. *Acad Med* 90: 1457–1461, 2015.
27. **Mayer RE.** *Multimedia Learning*. Cambridge: Cambridge Univ. Press, 2009.
28. **Mayer RE.** *The Cambridge Handbook of Multimedia Learning*. Cambridge: Cambridge Univ. Press, 2005.

29. **McNulty JA, Espiritu BR, Hoyt AE, Ensminger DC, Chandrasekhar AJ.** Associations between formative practice quizzes and summative examination outcomes in a medical anatomy course. *Anat Sci Educ* 8: 37–44, 2015.
30. **Merriam SB, Caffarella RS, Baumgartner LM.** *Learning in Adulthood: a Comprehensive Guide*. San Francisco, CA: Jossey-Bass, 1999.
31. **Merrill MD.** First principles of instruction. *Educ Technol Res Dev* 50: 43–59, 2002.
32. **Miller GA.** The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychol Rev* 63: 81, 1956.
33. **Paas FG, Van Merriënboer JJ.** Variability of worked examples and transfer of geometrical problem-solving skills: a cognitive-load approach. *J Educ Psychol* 86: 122, 1994.
34. **Paas FG, Van Merriënboer JJ, Adam JJ.** Measurement of cognitive load in instructional research. *Percept Mot Skills* 79: 419–430, 1994.
35. **Paivio A.** *Mental Representations: a Dual-Coding Approach*. New York: Oxford Univ. Press, 1986.
36. **Reigeluth CM.** The elaboration theory: guidance for scope and sequence decisions. *Instruct Design Theories Models* 2: 425–453, 1999.
37. **Rushton A.** Formative assessment: a key to deep learning? *Med Teach* 27: 509–513, 2005.
38. **Schuwirth LW, Van der Vleuten Cees PM.** Programmatic assessment: from assessment of learning to assessment for learning. *Med Teach* 33: 478–485, 2011.
39. **Susilo AP, van Merriënboer J, van Dalen J, Claramita M, Scherpbier A.** From lecture to learning tasks: use of the 4C/ID model in a communication skills course in a continuing professional education context. *J Contin Educ Nurs* 44: 278–284, 2013.
40. **Sweller J.** Cognitive load during problem solving: effects on learning. *Cogn Sci* 12: 257–285, 1988.
41. **Sweller J, Chandler P, Tierney P, Cooper M.** Cognitive load as a factor in the structuring of technical material. *J Exp Psychol Gen* 119: 176, 119.
42. **Sweller J, Van Merrienboer JJ, Paas FG.** Cognitive architecture and instructional design. *Educ Psychol Rev* 10: 251–296, 1998.

42a. **Taras M.** Assessment–summative and formative–some theoretical reflections. *Br J Educ Stud* 53: 466–478, 2005.

43. **Torre DM, Daley BJ, Sebastian JL, Elnicki DM.** Overview of current learning theories for medical educators. *Am J Med* 119: 903–907, 2006.
44. **Van Merriënboer JJ.** *Training Complex Cognitive Skills: a Four-Component Instructional Design Model for Technical Training*. Englewood Cliffs, NJ: Educational Technology Publication, 1997.
45. **Van Merriënboer JJ, Clark RE, De Croock MB.** Blueprints for complex learning: the 4C/ID-model. *Educ Technol Res Dev* 50: 39–61, 2002.
46. **Van Merriënboer JJ, Kirschner PA, Kester L.** Taking the load off a learner's mind: Instructional design for complex learning. *Educ Psychologist* 38: 5–13, 2003.
47. **Van Merrienboer JJ, Sweller J.** Cognitive load theory and complex learning: Recent developments and future directions. *Educ Psychol Rev* 17: 147–177, 2005.
48. **Van Merriënboer JJ, Sweller J.** Cognitive load theory in health professional education: Design principles and strategies. *Med Educ* 44: 85–93, 2010.
49. **Wittrock MC.** Generative processes of comprehension. *Educ Psychologist* 24: 345–376, 1989.
50. **Young JQ, Van Merrienboer J, Durning S, Ten Cate O.** Cognitive load theory: Implications for medical education: AMEE guide no. 86. *Med Teach* 36: 371–384, 2014.
51. **Zimmerman BJ.** Achieving academic excellence: a self-regulatory perspective. *Pursuit Excellence Educ* 2002: 85–110, 2002.
52. **Zimmerman BJ.** Self-regulated learning and academic achievement: an overview. *Educ Psychologist* 25: 3–17, 1990.