Chapter LXVI
Instructional Game Design Using Cognitive Load Theory

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ABSTRACT

This chapter proposes an instructional game design framework based on the 4C/ID-model and cognitive load theory, its associated theoretical foundation. The proposed systematic design framework serves as the processing link to connect games' powerful characteristics in enhancing learning experience with desired learning outcomes. In this chapter we focus on the cognitive aspect of learning outcome: the development of transferable schema. This chapter introduces design guidelines to attain specific game characteristic by prioritizing the design components in 4C/ID-model. Each game characteristic consists of three levels of design emphasis: preliminary, secondary, and tertiary. The ultimate goal of this chapter is to initiate a series of dialogue between cognitive learning outcome, systematic instructional design, and instructional game design thereby seeking to improve the overall game design and instructional efficiency.

INTRODUCTION

In recent years, the use of games for teaching and learning has grown significantly in the training industry and K-16 educational settings. There is, however, a lack of understanding between what games readily provide (i.e., games' characteristics) and what the learners need from games (i.e., learning outcome). Such deficiency makes it difficult for instructional designers to systematically apply a design framework as well as to justify their decisions in using games to enhance learning. Being equipped by their multi-dimensional characteristics, the instructional potential of games therefore cannot be fully utilized until there is substantive evidence linking specific instructional benefits to various game characteristics. Moreover, the lack of systematic instructional game design process supports unnecessarily prolonged, costly, and inefficient game design.

Games today are usually designed and developed based on generic film production procedures as well as filmmakers' mental models. Entertaining *is* the key design *objective*. All actions taken in game design are focused on one reason: to entertain the players. But what happens if we are to design instructional games? Does the entertainment element still override everything? While this key objective works for game developers, if games are to become a viable tool with instructional value, games need to more than entertain, they need to facilitate learning. This chapter believes that the design focus should be shifted to enhancing learning experience while still utilizes entertainment to support learner engagement. The ultimate goal of designing instructional games is to preserve the complex nature of games in order to optimize their impact on learning. The lack of a systematic design framework, however, often leaves some games' learning-enhancing features unexplored. As a result, instructional games' capabilities are not fully manifested for the purposes of enhancing learning and learning transfer to performance settings.

The purpose of this chapter is to describe a systematic instructional game design framework to address the issues just presented. We identify the cognitive load theory-based 4C/ID-model as the prototypical model to base the instructional game design framework, emphasizing the 4C/ID-model's focus on schema construction for complex learning and performance transfer. The following sections first discuss games' characteristics based on previous studies. Second, the chapter introduces the 4C/ID-model in the context of cognitive load theory; and third we propose an instructional game design framework based on 4C/ID-model to attain specific game characteristics in support of complex cognitive learning. Finally, the chapter proposes a design framework for future research with the intention to initiate meaningful dialogue on how we can empirically investigate the learning impact of instructional games.

BACKGROUND

What Are Games

A game is a context in which individual and teamed players, bounded by rules and principles, compete in attaining identified game objectives. There is a series of decision-making processes are required by the game players. Elliot Avedon and Brian Sutton-Smith (1971) explained that game playing is a voluntary exercise of controlling a system (i.e., the game) intended for a state of disequilibrium. In other words, game players continuously try out new methodologies and strategies during the game-playing process based on the system's feedback until they achieve the game objectives or the equilibrium state. The following section explains several game components that include:

- Games create experiences
- Rules and interactions in games
- Games are complex
- Games are models

Games Create Experiences

Games are known for their capabilities to promote collaborative and active learning (Downes, 2004; Klabbers, 2006; Vygotsky, 1978). Game players learn from their success and mistakes in order to improve their gaming skills and playing strategies. Players learn about the games and how to win the games from playing games and reflecting on the game interactions. The process begins with concrete playing experience. Players observe how the system responds to their actions in the form of scoring. Players then revise their playing strategies and try them out at similar situations. A player can play the game many times and never quite get the gist of the game (experience along is not sufficient). At some point, however, a player who thinks about what they are trying to learn (reflection and self feedback) can begin to master the game.

Rules and Interactions in Games

Games requiring individual participation offer a rich environment for players to be interactive with the game system (UNIGAME, 2002). Games comprise a system that consists of rules, process, and interactions that players must experience in order to attain desired outcome. Game rules help players connect the game contexts with players' existing schema; they also impose limits and guidelines on actions and to ensure that all players are seeking to achieve the game goals. Rules represent the criteria for evaluation of the player performance in the form of scoring, as well as to acknowledge players' performance during the game-playing process. Rules further enable players to analyze the interrelationships between different rules to generate feasible and "winning" strategies (Bennett & Warnock, 2007; Björk & Holopainen, 2003; Garris, Ahlers, & Driskell, 2002; Hays, 2005; Leemkuil, de Jong, & Ootes, 2000). Interactions in games are considered as structural components allowing players to interface with other players, game context, and the system. It is the interaction component that makes the game rules and the playing process meaningful (Asgari , 2005; Crawford, 1982; de Felix & Johnson, 1993; Kirriemuir & McFarlane, 2006; McGrenery, 1996; Myers, 1990; Thornton & Cleveland, 1990; Waal, 1995) The interactions within a game allow players to directly acquire first-hand experience thereby helping them to learn about the system presented in the game.

Games Are Complex

An engaging game can be more complex than a boring game. Players must consider multiple factors before finalizing a winning decision. Sim City™, for example, players are responsible for planning, developing, and sustaining a prospering city. Building a new hospital is usually an effective strategy to attract new residents to move to the "simulated" city. The decision-making process for players is everything but simple and straightforward. One game play or action could impact the overall outcome since all pieces are causally connected by the game rules and system. Games are capable of linking critical elements together and hence can create a complex learning environment, that helps learners see the complex nature of a given model and also can help to develop transferable and predictive problem-solving strategies (Björk & Holopainen, 2003).

Games Are Representations Models

Games can embody abstract concepts and rules. The winning game play or game strategy is the translation of problem-solving strategies intended by the game model. The game adds contextual information to the model as to how to apply the information in different situations. This contextual information is often represented by a story line which implicitly or explicitly guides the players throughout the process. Simulation games, for example, are powerful in creating authentic situations for players to experience realistic and immediate performance feedback. Learners playing simulation games can directly interfacing with the intended model in a tangible way (Bennett & Warnock, 2007; Björk & Holopainen, 2003; Garris et al., 2002; Hays, 2005; Leemkuil et al., 2000).

Gaming Characteristics

An exhaustive literature review has identified 11 prominent and yet interrelated characteristics found in games regardless of their delivery formats. Each game characteristic is described in Table 1.

Challenge

A challenging activity provides an achievable level of difficulty for game players that consists of clearly identified task goals, unpredictability, immediate performance feedback, and a sense of accomplishment and conquering after completing the activities (Baranauskas, Neto, & Borges, 2001; Belanich, Sibley, & Orvis, 2004; Bennett & Warnock, 2007; Csikszentmihalyi, 1990; Garris et al., 2002; Malone, 1981; Malone & Lepper, 1987; McGrenery, 1996; Rieber & Matzko, 2001).

Competition

Competition stimulates players to take risk-taking actions in a consequence-free environment enriched with social interactions. Players develop their skills during the game-playing process by matching and exceeding the opponents' skill levels. The competition can be implemented between individual players, among teams, and even between players and the system (Baranauskas et al., 2001; Crawford, 1982; Csikszentmihalyi, 1990; Leemkuil et al., 2000; Rieber & Matzko, 2001; Vockell, 2004).

Rules

Rules of games serve as the guidelines for players' actions. Fair play is also sustained by the enforcement of game rules. Players need to learn about the game rules either by designated training or via the actual playing experience. In the context of games for learning, game rules could be the direct or indirect translations of intended instructional materials such as scientific concepts of economic principles (Bennett & Warnock, 2007; Björk & Holopainen, 2003; Garris et al., 2002; Hays, 2005).

Goals

Goals in games clearly state the final status for players to attain via a series of planned tasks and actions by following the game rules. Sub-goals in games are often presented to present various stages of accomplishment for motivational and evaluation purposes. The presence of goals is also the major difference between games and simulations (i.e., simulations could be goal-less) (Bennett & Warnock, 2007; Björk & Holopainen, 2003; Csikszentmihalyi, 1990; de Felix & Johnson, 1993; Gredler, 1996; Hays, 2005; Hirumi, 2006; Leemkuil et al., 2000; Malone, 1980).

Fantasy and Changed Reality

Fantasy creates entirely unreal situations and environments for game players. This characteristic encourages players to take risks in a safe environ-

Table 1. Game characteristics

1.	Challenge	7.	Engagement and Curiosity
2.	Competition	8.	Role-Playing
3.	Rules	9.	Control
4.	Goals	10.	Multimodal Presentation
5.	Fantasy and Changed Reality	11.	Task
6	Story or Representation		

ment. Fantasy also motivates players to follow the story line to achieve desired game goals (Bennett & Warnock, 2007; Garris et al., 2002; Kirriemuir & McFarlane, 2006; Malone, 1981; Malone & Lepper, 1987; McGrenery, 1996). Changed reality in games allows players to have exaggerated experiences in a specific context, which must reflect a certain degree of reality, but not entirely. Usually changed reality separates itself from reality by altering time, space, role-playing, and the complexity of situations (e.g., simplified reality) (Belanich et al., 2004; Björk & Holopainen, 2003; Crawford, 1982; Csikszentmihalyi, 1990).

Story or Representation

Story line or representation in games provides paths for players to interact, react, and progress. It summarizes the game goals, rules, constraints, role playing, and contexts for players in a seamlessly interconnected and embedded fashion (Hirumi, 2006; Rieber & Matzko, 2001). Players usually favor the representation of game rules in stories since it not only informs them the game guidelines, but also provides a holistic view of the entire game context.

Engagement and Curiosity

Engagement created by games allows players to become deeply involved in the game where players lose their sense of realistic self. In other words, players perceive themselves as part of the game and enjoy the intrinsically motivating game-playing experiences. Playing the game itself is rewarding enough without extrinsic motivators. Implementing elements of mystery and curiosity is also considered effective in creating engaging game experiences (Asgari, 2005; Bennett & Warnock, 2007; Csikszentmihalyi, 1990; Leemkuil et al., 2000; Malone, 1980; Malone & Lepper, 1987; McGrenery, 1996).

Control

Control in games enables players to determine and predict the outcome of actions or events. Providing options or choices to players, for example, is an effective approach to allow players to exercise control over the game progression (Belanich et al., 2004; Bennett & Warnock, 2007; Csikszentmihalyi, 1990; Garris et al., 2002; Gredler, 1996; Malone, 1981; Malone & Lepper, 1987; McGrenery, 1996; Waal, 1995).

Role Playing

Role playing in the game involves the player becoming a character embedded in the story line of the game. Usually the player's role is pre-identified with specific position, access to resource and control, dominance over the progression of the game, functionality (if within a team), and behavioral patterns. Role playing helps players establish connection with the fantasy world of the game in order to better engage players with the game-playing experience (Björk & Holopainen, 2003; Gredler, 1996).

Multimodal Presentation

Games usually utilize multimodal presentation to effectively enhance the interest and instructional effect. This is particularly true in video games. Aural, visual, and textual presentations are combined in order to enrich the experience. Animations, for example, are popular as a major game component since they seamlessly integrate multimodal presentations and can be easily modified for different game contexts (Bennett & Warnock, 2007; Björk & Holopainen, 2003; de Felix & Johnson, 1993; McGrenery, 1996).

Task

Within the game mission, there are several tasks that comprise the building block of a game's goal.

Players often are required to take on sequences of tasks in order to achieve the game's final goals. Task feedback or performance scores serve as player assessment of accomplished tasks that help players improve their playing strategies (Björk & Holopainen, 2003; Gredler, 1996). Games tasks can be derived from a learning task analysis and can be used to help players reach of intended learning goals.

PROBLEM

In addition to the aforementioned finding on game characteristics, the literature review (Johnson, Spector, Huang, & Novak, 2007) did not reveal a systematic nor pedagogically sound design model available for optimizing games' effects on learning. Further, there was no evidence that suggested that a specific gaming characteristic or gaming strategy was linked to a specific learning goal. Given the multi-dimensional and multi-layered characteristics of games, the lack of practical design model diminishes the power of the game design to supporting complex learning and also prolongs the design cycle.

The absence of empirical design model for instructional game also poses an immediate concern to the evaluation of games' pedagogical impact. A majority of studies on games and their impact on learning are conducted as post-hoc analyses (O'Niel, Wainess, & Baker, 2005). Without a validated design model to purposefully control the inclusion and exclusion of design elements based on intended learning outcome, it is only possible to speculate the linkage between game characteristics and desired learning outcomes (O'Neil et al., 2005).

SOLUTION

In order to enhance the decision-making associated with game design, we propose that game designers use the underlying principles found in the 4C/ID-model (van Merriënboer, & Sweller, 2005). This model is based on cognitive load theory (Chandler & Sweller, 1991; van Merriënboer & Paas, 1998), to address several of the concerns presented. The 4C/ID-model is suitable for designing and researching instructional games due to the model characteristics that include:

- Affordability to design complex learning environments;
- Flexibility to be applied for non-linear and compact design sequence;
- Scalability for design projects in various scopes;
- Validity and reliability of measuring learning outcome; and
- Emphasis on performance transfer.

Cognitive Load Theory

Cognitive load theory (CLT) (Chandler & Sweller, 1991; van Merriënboer & Paas, 1998) has established a sound theoretical foundation to connect cognitive research on human learning with instructional design and development (van Merriënboer, Clark, & de Croock, 2002). The purpose of CLT is to bridge the gap between information structures presented in the instructional material and human cognitive architecture so learners can use their working memory more efficiently (Paas, Renkl, & Sweller, 2003). "Learning," in the context of CLT, is thought to involve acquisition and automation of schema. Acquisition of schema is the process of how learners construct schema and store them in long-term memory, whereas automation is how learners perform certain tasks without accessing working memory. Information required for the performance of a task is retrieved directly from the long-term memory (Paas et al., 2003). Successful construction and automation of schema will lead to a more efficient use of working memory for desired performance since both attributes require little working memory capacity and yet are critical to meaningful learning (Mayer, 2001).

Three types of cognitive load are suggested by CLT to construct cognitive load: intrinsic cognitive load, extraneous cognitive load, and germane cognitive load. When combined, the three types of cognitive loads compose the total cognitive load, which can never exceed learner's working memory capacity for learning to occur. The total of extraneous cognitive load and germane cognitive load is assumed to be equal to the overall cognitive load minus the intrinsic cognitive load. Since the intrinsic cognitive load is fixed (i.e., the load cannot be manipulated by instructional design), instructional design's main purpose is to reduce the extraneous cognitive load while increasing the germane cognitive load (van Gerven, Paas, van Merriënboer, & Schmidt, 2003).

Intrinsic cognitive load is associated with the element interactivity inherent to the instructional material itself. Element interactivity is described as the degree to which information can be understood alone without other elements' involvement (Paas et al., 2003). As suggested by Paas et al. (2003), information with high element-interactivity is hard to understand because it usually depends on the involvement of other information units in order to see the full interaction. Therefore, instructional material with high element interactivity is assumed to induce a higher intrinsic cognitive load since the instruction requires more working memory for information processing (Pass et al., 2003). The intrinsic cognitive load is also considered to be independent of instructional manipulations because the manipulation only involves the amount of information a learner needs to hold in working memory without decreasing the inherent element interactivity (Pollock, Chandler, & Sweller, 2002). The extraneous cognitive load and germane cognitive load, in contrast, can be manipulated by instructional design (Brünken, Plass, & Leutner, 2003).

Extraneous cognitive load is also known as *ineffective cognitive load* as it only involves the process of searching for information within working memory as opposed to the process of constructing schemas in long-term memory (Paas et al., 2003). This type of cognitive load can be influenced by the way information is presented and the amount of working memory required for given learning tasks. The extraneous cognitive load is considered as the necessary cost of processing information that is not related to the understanding of information. Instructional design's purpose therefore is to reduce the ineffective (i.e., extraneous) cognitive load (Brünken et al., 2003). Well-designed instructional multimedia components have been found to be effective in reducing the extraneous cognitive load (Khalil, Paas, Johnson, & Payer, 2005a, 2005b; Mayer & Moreno, 2003). Cobb (1997) suggested similar multimedia application in designing instructional materials to increase "cognitive efficiency, where he used multimedia component (non-verbal and non-textual components) as cognitive capacity external to learners' working memory, to facilitate cognitive information processing. Consequently learners should spend less cognitive effort in understanding given information.

In contrast to the desired low degree of the extraneous cognitive load, instructional materials should be designed to increase the germane cognitive load. The germane cognitive load, also known as *effective cognitive load*, is described as the effort learners invest in order to facilitate the process of constructing schema and automation (Paas et al., 2003). Higher germane cognitive load is suggested to lead to a deeper learning since learners are compelled by the design of the instructional material to reexamine every new piece of information (de Crook, van Merriënboer, & Paas, 1998).

In summarizing CLT, the overall goal of manipulating cognitive load with instructional design is to decrease the level of ineffective cognitive load (i.e., extraneous cognitive load) and to increase the effective cognitive load that promotes deeper learning (i.e., germane cognitive load) (Paas et al., 2003). The CLT further suggests that the combination of extraneous and germane cognitive load should remain relatively constant after removing the fixed intrinsic cognitive load (Paas et al., 2003). The decrease of extraneous cognitive load should lead to the increase of germane cognitive load, or vice versa (Paas et al., 2003; van Gerven et al., 2003).

In order to better apply CLT in practical instructional design, van Merriënboer, Clark, and de Croock (2002) proposed the four-component instructional design system (4C/ID-model) for designing complex learning environments (van Merriënboer & Sweller, 2005). The following section will discuss the 4C/ID model in detail and its applicability in designing complex game-based learning environments.

4C/ID-model (Four Components/ Instructional Design Model)

4C/ID-model is a non-linear, systematic, integrated, and performance transfer-oriented instructional design model intending to reduce extraneous cognitive load while increasing germane cognitive load during the learning process in complex learning environments. The model includes four non-linear, interrelated design components: *learning tasks, supportive information, just-in-time (JIT) information, and part-task practice*. All design actions center around the learning tasks component.

Learning tasks are concrete, authentic, whole-task experiences that are provided to learners to promote schema construction for non-recurring aspects and, to a certain degree, rule automation. Learning tasks must be complex and require the coordination and integration of all constituent skills. Task classes are used to define simple-to-complex categories of learning tasks and to steer the process of selection and development of suitable learning tasks. Learning tasks within a particular task class are equivalent in the sense that the tasks can be performed on the basis of the same body of knowledge (i.e., mental models and cognitive strategies). Learners are required to elaborate upon their existing knowledge base when given a higher task class. Various supports are also provided with learning tasks. Learner support informs learners about the problem in hand and guidance for generating effective solutions; product-support provided solution models in terms of worked-out examples and case studies; process-oriented support explains performance requirement and criterion reference for learners. The design should primarily aim at the induction process. That is, the design should focus on constructing schemata through attentive abstraction from the concrete.

Supportive information mainly supports the learning and performance of non-recurring aspects of intended tasks. Theories and models are often included in supportive information since learners can apply them universally for problem-solving in the same task class. The design of learning environments aims at the construction of meaningful relationships between learners' prior experiences and the learning tasks with experiential approach. More importantly the design should promote the elaboration process with cognitive feedback (Reigeluth, 1999) thus to enable learners to develop complex schemata.

JIT information facilitates learners' development in generating automated responses. Rules and principles are embedded in this design component and applied with the part-task practice. This design component uses demonstrations and instances to effectively explain the rules for all classes of learning tasks.

Part-task practice promotes rule automation for selected recurrent aspects of the intended complex task. The design approach aims to gradually develop learners' ability to automate the performance of recurrent skills via small task building blocks.

In addition to help learners develop desired skill levels separately, the 4C/ID-model stresses the integration and coordination of different levels of skills with intentional design, which traditional ISD models seem to lack. The main design goal of 4C/ID-model is to situate learners in authentic, complex learning environments with realistic contexts. The attainment of desired performance is more than just "assembling parts" together. Efforts also should go into the identification, evaluation, selection, combination of learned separated skills (constituent skills), to solve complex problems. 4C/ID-model suggests the necessity to purposefully design the relationships among different constituent skills (i.e., the outcome of task analysis) in complex learning environments. The relationships could be temporal as desired tasks need to be performed step-by-step; it is also possible that learners need to demonstrate proficient performance on different task procedures simultaneously (e.g., air traffic controllers must monitor multiple aircrafts at the same time).

The model operates under these assumptions: (1) an upper level learning skill can be attained by assembling sets of simplified task procedure; and (2) performance transfer can be easily achieved after completing simplified learning tasks (van Merriënboer & Sweller, 2005). It further divides constituent skills in general into two categories: non-recurrent skills and recurrent skills. Non-recurrent skills morph themselves from problem to problem. As a result they require learners' cognitive reasoning since every situation is different from their previous experiences. Cognitive strategies are applied to extract existing schema in order to facilitate the problem-solving process in a novel context. Recurrent skills, on the other hand, are less effortful for learners to process and perform. Problem-solving process, in the case of recurrent skills, is very close to what learners have experienced before.

The design of the learning environment should focus on the abstraction of effective problem-solving process for non-recurrent skills since the goal is to enable learners to redevelop their own schema under various scenarios. In other words, the abstraction helps learners transfer the desired performance from context to context. The design approach proposed by this model is to provide concrete cases for learners to fully experience the cycle of abstraction and schema redevelopment. Additionally supportive information is utilized as one of the design component, to facilitate the development of non-recurrent skills, which will be discussed later in this section. When designing for recurrent skills, authentic and full application of rules and principles is crucial. The goal is to help learners automate the desired performance procedures with the least effort. This model proposes a layer-by-layer approach to compile rules and procedures in the form of part-task practices. The entire task is dissected into interrelated part-task practices and learners are only asked to finish one of them at a time. The repetitive application of rules in order to accomplish all the part-task practices strengthens learners' automated responses toward similar problems. Moreover learners should have spontaneous access to rules and principles while accomplishing part-task practices. The just-in-time (JIT) information thus is proposed in the design model to facilitate the automation development process. By addressing both aspects of skill sets with 4C/ID-model's design approaches, learners will be able to transfer the desired performance efficiently into different contexts.

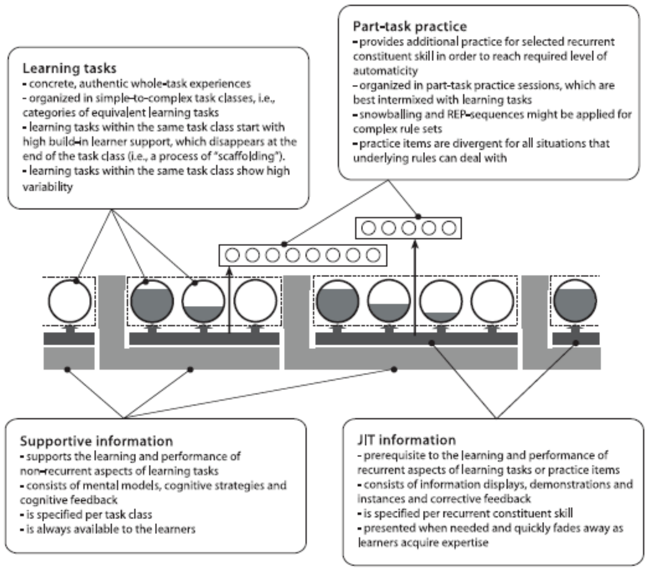
See Figure 1 for the visual presentation of the 4C/ID-model (van Merriënboer et al., 2002).

USING 4C/ID FRAMEWORK FOR GAMING DESIGN

In this section we describe use of the 4C/ID-model as the framework to compare the design components with games' characteristics in order to answer following questions:

- What game characteristics, based on previous literature reviews, should be able to directly support cognitive learning?

Figure 1. Visual presentation of the 4C/ID-model (in van Merriënboer, Clark, & de Croock, 2002, p. 44)



- How are design components of 4C/ID-model capable of informing the design of specific game characteristic?

Game Characteristics and Cognitive Learning

Cognitive learning, as described in the context of cognitive load theory as well as the 4C/ID-model, mainly focuses on the construction of transferable schema (van Merriënboer & Sweller, 2005). Such construction requires integrations of interrelated knowledge units and problem-solving processes. Learners should be able to understand the relationship among them and be able to apply them effectively in different and most of the time, new, problem-solving situations. Learners not only construct new schema as the result of the learning process, but also relate, flex, and expand existing schema to make the learning experience more meaningful. The instructional information should be delivered as the building blocks for developing learners' cognitive structures in the forms of solved and unsolved cases, worked examples, process-explicit solutions, and so forth. Each building block is self-contained and yet interconnected with other pieces. The learning environment (i.e., instructional games) must help learners acquire what is included in each building block as well as how to assemble all building blocks together. Below is the list of game characteristics that can potentially support the schema construction process:

Challenge: To encourage learners explore and experiment new processes, in other words, to flex their existing schema.

Competition: Learners strive to facilitate the problem-solving process with effective solutions, in order to defeat the opponent(s), be it the game system, or competing units.

Rules: Rules in instructional games provide learners with information that guide the problem-solving process. They also can be composed in a way that requires learners to abstract and modify their existing schema.

Goals: Goals of instructional games oftentimes are not explicitly related to the cognitive tasks intended in the game. But they provide specific performance objectives for learners to pursue in the forms of scores, accomplished missions, and conquered territories. In another words, goals are the performance criteria of assessing learners' newly developed schema.

Fantasy and Changed Reality: This is where instructional games can flex learners' existing cognitive structure. Fantasy enables learners' imaginations based on their experiences. Learners voluntarily extract existing schema that might be useful to accomplish given tasks in the fantasized context. The difference between fantasy and changed reality is manipulated by the foreignness of the gaming context perceived by learners. Learner's prior experience plays a critical role in designing meaningful fantasy or changed reality in instructional games.

Story and Representation: This characteristic in games illustrates operational schema for learners. Ideally, a story contains a problem to be solved, resources required to solve a problem, conditions necessary to implement the solution, and the outcome of applying such solutions. In instructional games the story should be incorporated as the contextual information for learners to see the big picture of the game. Rules of the game can also be implicit in the storylines to guide the learners' actions.

Engagement and Curiosity: Engagement sustains learners' attention during the learning process while curiosity drives learners to explore and experiment. This set of game characteristic enables learners persistently expand their existing cognitive structure.

Role Playing: Role playing does not necessarily have to be in a fantasized context. Learners can be assigned with a completely different set of skills and environmental and situational characteristics to experience the instructional game. This game feature could enable learners to transfer problem-solving principles from role to role. It also familiarizes learners with various bodies of knowledge given different roles' diverse expertise.

Control: Learners prefer to control their own schema development processes. Self-pacing is one popular mechanism in playing games. Learners are able to monitor their progress in the process of achieving game goals with accumulated scores and number of mission accomplished.

Multimodal Presentation: This is an important game characteristic that affords effective manipulations of cognitive load during the learning process. Application and variation of multimodal presentation aims to reduce unnecessary usage of learners' cognitive capacity therefore facilitating schema development.

Task: Tasks represent a structure on which to construct schema for learners in instructional games. They are the building blocks of a game. Learners are required to accomplish sequenced or classed tasks in order to attain the final game goal. Each task encompasses all the aforementioned game characteristics in an operational form.

4C/ID-model Design Components and Game Characteristics

This section focuses on the process of using 4C/ID-model design components to create the instructional game environment, which bears the aforementioned game characteristics that are capable of facilitating cognitive learning process. Each game characteristic is paired with a primary component (denoted as 3 for highest priority), a secondary (denoted as 2) component, and tertiary design components (denoted as 1) from 4C/ID-model based on each component's definition to attain corresponding game characteristics. The radar graph in each game characteristic visually depicts the design priority we suggest. The combination of all components (learning tasks, part-task, supportive information, and just in time) aims to optimize the design outcome.

Challenge

Primary Design Component

Learning task is the main design focus to create a challenging game-based learning environment. Tasks are designed with various difficulty levels of attainable task objectives. Task variability also allows designers to manipulate the challenge levels of the learning environment.

Secondary Design Component

Supportive information needs to be carefully designed in order to create a challenging instructional game. The amount of supportive information available to learners in the game should be determined by learners' performance in prior tasks. Providing all supportive information to learners without performance analysis might reduce the level of challenge perceived by learners.

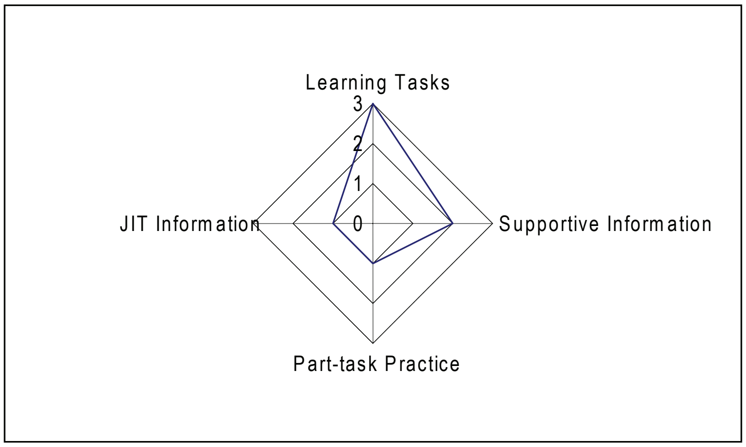
Tertiary Design Component

Part-task practice and JIT information are suggested to the tertiary design components.

Game Design Guideline for Challenge Characteristic

When creating learning games, designers need to focus on using varying levels of the learning task as the primary focus for creating a challenging game. If game challenge is based on other non-task factors, players will not spend the resources engaging in the critical tasks to be learned. Games need to engage and provide experiences related to the key learning tasks. Challenge can be presented in the form of a score or winning, but the score or success determinant needs to be directly related to the learning task. When designing game challenge, supportive information and part-task practice need to be aligned with learning tasks, thereby strengthening the learning focus of the game. The degree that these design features are present determines the degree of challenge. For example, if supportive information is present

Figure 2. Design emphasis for challenge



then the degree of challenge is less then when the supportive information is absent.

Competition

Primary Design Component

Competition requires immediate feedback on learners' performance as well as information regarding model performance or peer performance. Therefore the primary design components for this game characteristic include supportive information, that provides cognitive feedback, and JIT information that provides corrective feedback.

Secondary Design Component

Competition loses its attraction while every participant has similar skill level or resources as the result of practicing. Designers need to be cautious about not providing excessive part-task practices thus the competition feature can be fully demonstrated.

Tertiary Design Component

Learning tasks is the tertiary design component for this characteristic.

Game Design Guideline for Competition Characteristic

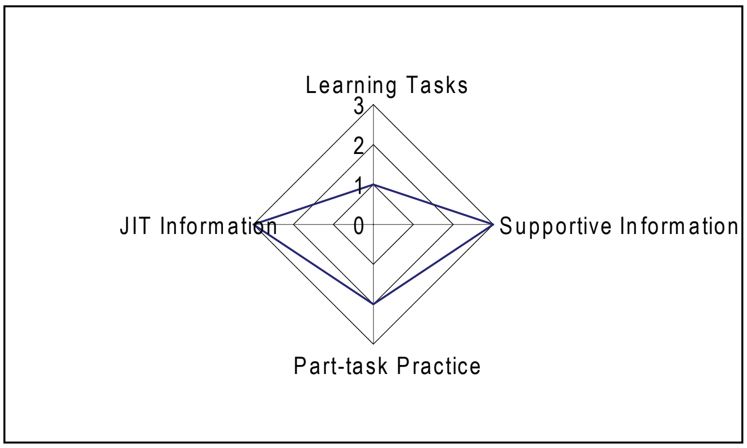
To facilitate game competition, players need to get immediate feedback on their performance. This feedback is presented primarily in the form of supportive information as well as JIT information. The learning tasks and the part-task practice are related to the game play, but not fundamental to enhancing the competition aspects of games. Competition is based on one player's interest compared to another player or a specified performance standard. The comparison information is either a score or performance feedback for both the player and the competition. This would be considered primarily supportive information. This information can be used as feedback to help the player regulate their level of game involvement.

Rules

Primary Design Component

Rule acquisition is best instilled via repetitive practice. In most cases game rules are translated from intended instructional information. Learners need to be able to automate the use of rules into

Figure 3. Design emphasis for competition



recurrent aspects of problem-solving tasks. Both supportive information and part-task practices are cable of achieving this game characteristic.

Secondary Design Component

Designers need to be cautious about inserting too much information about intended rules with the JIT information component. Although it is important to support learners' performance with the recurrent aspect of task by providing learners with JIT information such as rules, the instructional game should aim to develop learners' automation without any support external to learners' cognitive structures.

Tertiary Design Component

Learning task is the tertiary design component for this characteristic.

Game Design Guideline for Rules Characteristic

One of the first tasks in game playing is learning the rules. Once the rules are acquired, players are able to formulate appropriate decision making to compete successfully. Facilitating players' development of games rules is important. Providing supportive information as well as part-task practice can facilitate rule acquisition. Supportive information is direct and can quickly support rule acquisition. Practice allows players to test out their understanding and revise their rule models. Rules as part of JIT information does not give learners the information at the decision making and strategic point. Plus the use of the rules needs to become automatic for the learners. Optimal task performance occurs as part of the players having a fluent understanding of the game rules.

Goals

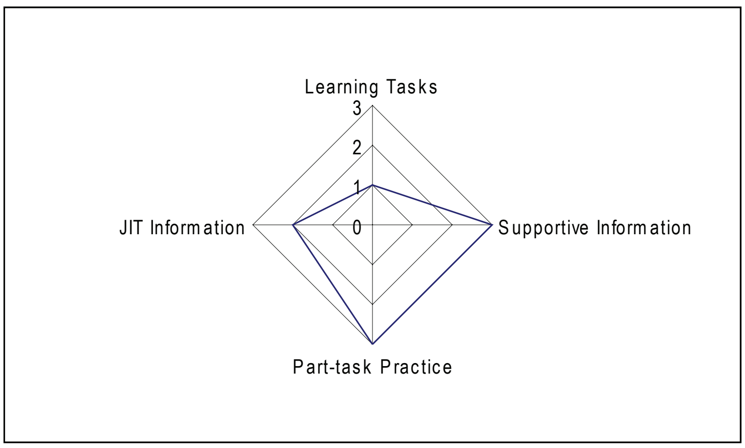
Primary Design Component

Goals should be identified in the learning task. The game goals should directly connect to the learning goals with explicit rationales.

Secondary Design Component

Supportive information and JIT information need to provide cognitive as well as corrective feedback to ensure learners are staying on the right track to attain the game goal.

Figure 4. Design emphasis for rules



Tertiary Design Component

Part-task practice is the tertiary design component for this characteristic.

Game Design Guideline for Goals Characteristic

Of the various components of the 4C/ID model, learning tasks need to be aligned with the game goals. If the game goals and the learning tasks are not parallel, then the game goals that drive the game play will be more deliberate thereby diminishing the learning tasks.

Fantasy, Changed Reality, and Role Playing

Primary Design Component

The design of learning task is the key component for this characteristic. Contextual information in each learning task enables learners to situate themselves into the specific game setting.

Secondary Design Component

Designers need to make sure that supportive information can provide additional support for

Figure 5. Design emphasis for goals

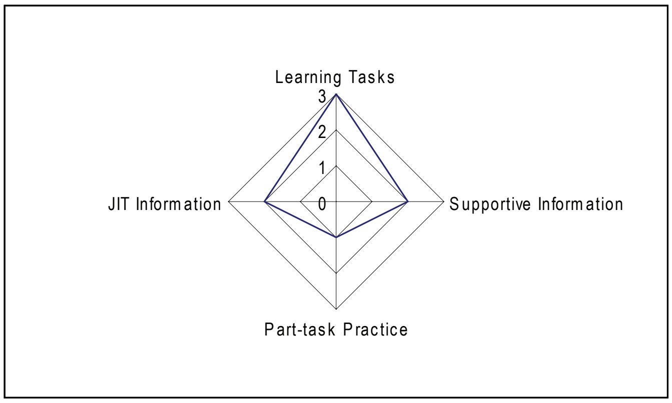
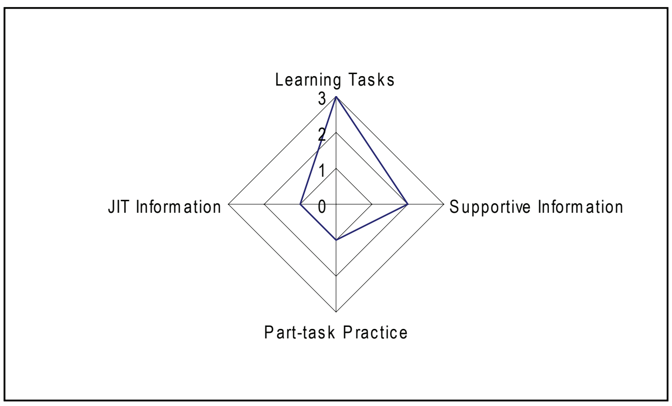


Figure 6. Design emphasis for fantasy, changed reality, and role-playing



learners to be able to operate effectively in the fantasy world. Common senses or general knowledge might not be sufficient to accomplish given tasks in an unrealistic context.

Tertiary Design Component

Part-task practice and JIT information are the tertiary design components for this characteristic.

Game Design Guideline for Fantasy, Changed Reality, and Role-Playing Characteristic

Learning task and to a lesser extent supportive information are important in the development of these game characteristics. The context of the learning tasks will support or weaken the intended setup for fantasy, reality, or role play. The critical element in making the set-up believable is that both the task and supportive information are aligned with the intended environmental setup.

Story and Representation

Primary Design Component

Designers should focus on the learning task for this characteristic. In addition to emphasize individual tasks' function to contain necessary elements in order to complete certain pieces of the story, this part of the design also needs to focus on the connectivity between tasks. Thus learners are able to assemble all pieces together and finish the story.

Secondary Design Component

Similar to the design of fantasy or changed reality, designers should to provide sufficient background information for learners to see the whole story line as soon as possible. Supportive information should be designed closely with the background story of learning task.

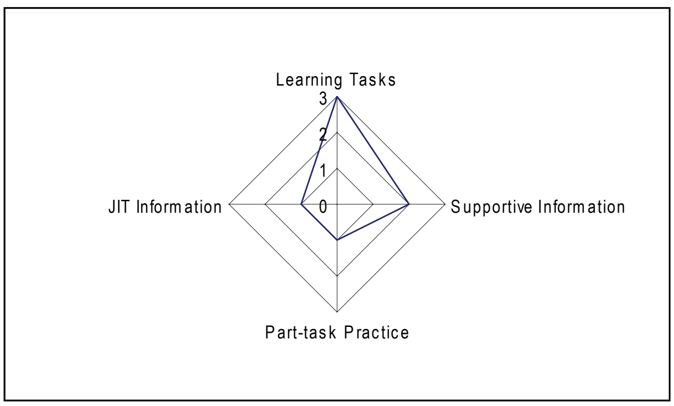
Tertiary Design Component

Part-task practice and JIT information are the tertiary components.

Game Design Guideline for Story and Representation Characteristic

Similar to fantasy, reality, or role play, the contextual setting for the learning task needs to be primarily considered in the creation of the story or game representation. Aligning the game design with the learning task will impact the quality of the overall game story and representation.

Figure 7. Design emphasis for story or representation



Engagement and Curiosity

Primary Design Component

The design focus should aim to maintain learners' interests in continuing participating in the game-playing process. From the viewpoint of cognitive learning, the learning environment needs to be relevant to learners' prior experience and be able to attract learners' attention in the initial stage of the learning process. Therefore the JIT information needs to be emphasized since it provides learners with support on prerequisite information, which must closely aligned with the learning task.

Secondary Design Component

Given the complexity involved in creating an engaging instructional game, designers should focus on the learning task and supportive information to continuously guide learners to explore new ways of processing information as well as to stretch their existing cognitive structure.

Tertiary Design Component

Part-task practice is the tertiary design component for this characteristic.

Game Design Guideline for Engagement and Curiosity Characteristic

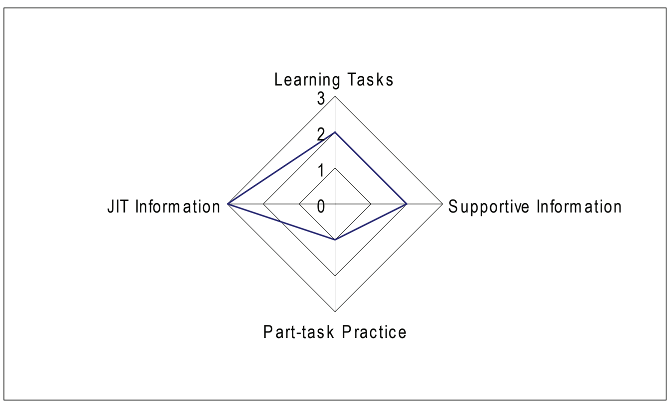
Engagement and curiosity can be support with JIT information. This type of information can provide players with assistance to decrease frustration levels as well as prompt players with hints about the specific game play. By providing JIT information, players are given information to string them along the game and facilitate their personal interest and curiosity.

Control

Primary Design Component

In order to perceive their full control in a game, learners want to have options in actions taken in a game. Players also need consistent and meaningful feedback from the system and other game participants to support decision-making to best help maintain control. The emphasis of design lies with supportive information for its cognitive feedback and JIT information for its corrective feedback.

Figure 8. Design emphasis for engagement and curiosity



Secondary Design Component

Learning task should be designed to offer learners multiple paths to solve one problem. Clear performance indicator during the game playing process also needs to be included (e.g., performance scores, enemies defeated, etc.).

Tertiary Design Component

Part-task practice is the tertiary design component for this characteristic.

Game Design Guideline for Control Characteristic

The learning task is predefined and offers little control for the player outside of the standard learning task steps. However the JIT information as well as the supportive information provide players with information about how they can better control the game play as well as giving them information about the game options thereby allowing them to control the decision-making tasks, thereby ultimately giving them control over the game. This is akin to the saying, "knowledge is power."

Multimodal Presentation

This design principle can effectively reduce the overall cognitive load induced by the game-based learning environment. Designers need to be extremely cautious about not overloading learners' cognitive load with abundance of multimedia stimuli. Rather, multimedia components should be utilized in a way to serve as the peripheral cognitive capacity for learners to process information.

Game Design Guideline for Multimodal Presentation Characteristic

While multimodal refers to varying types of media, the 4C/ID-model automatically considers multimodal strategies: learning tasks, supportive information, JIT information, and part-task practice. These four components are collectively considered multimodal. Each one is unique, yet they all are focusing on different aspects of the game environment. In considering the components, this will allow the player game support from multiple directions.

Figure 10. Design emphasis for control

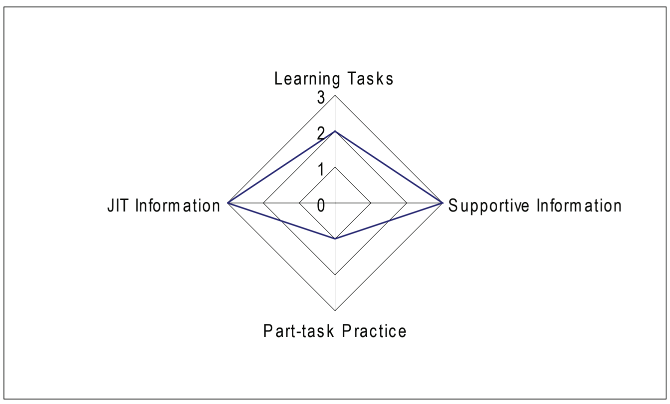


Figure 11. Design emphasis for multimodal presentation

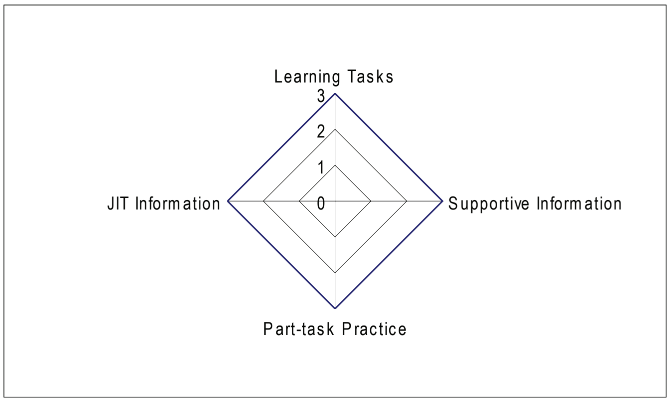
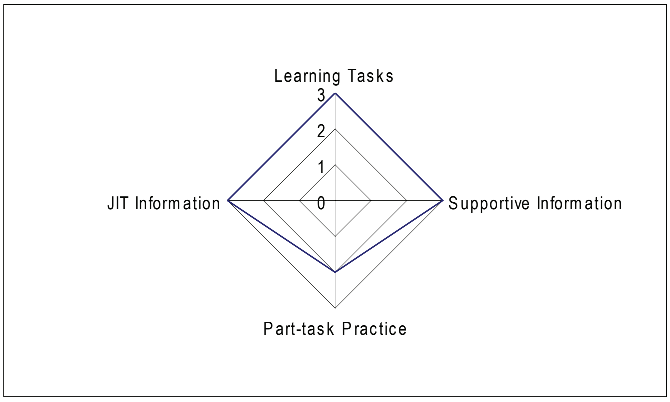


Figure 12. Design emphasis for tasks



Task

Primary Design Component

Similar to what 4C/ID-model suggested, tasks are the central piece of the design for most of the games. Game task is the embodiment of schema that learners must develop as the result of the learning process. The interconnection between game tasks is equally important as the content within each game task. Designers should focus on the learning task component for this characteristic. Additionally the supportive information and JIT information must be sufficient to provide the connection between all tasks, to develop learners' fluidity in applying intended skill sets to different contexts.

Secondary Design Component

Part-task practice can be inserted between main game tasks to reinforce the automation of intended skills.

Game Design Guideline for Tasks Characteristic

This game characteristic focuses on the game task. As mentioned earlier, the learning task ideally needs to be aligned with the game task. In as much as these two are similar, the game design will enable players to simultaneously engage in learning during the game-play periods.

CONCLUSION

This chapter, based on cognitive load theory and the 4C/ID-model, proposes a systematic design framework for designing pedagogically sound instructional games. The ultimate goal is to initiate series of empirical inquiries on how designers can link game characteristics with intended learning outcome via systematic design processes.

IMPLICATIONS

The adoption of 4C/ID-model not only presents viable opportunities for designing pedagogically sound games, but also reminds us the need for rigorous design research to continuously examine existing instructional design models for instructional game design and more importantly, to identify innovative design models and theories across disciplines. For example, Johnson (2001) proposed the "emergence perspective" to advocate a decentralized and multi-lateral system design approach based on his observations on ant colonies and human cities, which is considered an efficient design approach for video games (Irlbeck, Kays, Jones, & Sims, 2006). The feedback generated by the interactions between existing design model components, intended learning outcome, and preferred game characteristics should guide the overall design process, as opposed to following rigid and linear steps seen in conventional instructional design approach.

FUTURE TRENDS

In terms of systematic design process for developing instructional games, it is likely to see more streamlined process emerging from the field. We also anticipate more joint effort between computer science, learning technologies, and the game industry. The key is to connect theories of learning with design practices that are feasible by current industry standards for many reasons. First and foremost is to promote instructional games as efficient tools to enhance learning experience and to sustain improved performance. Second, designers want to be able to make design decisions with strong empirical support on the pedagogical effect of instructional games. Third, industry wants to be able to manage the design and development process with more efficiency and confidence.

On the research front of investigating instructional games' impact on learning and performance, we foresee research frameworks consist of all aspects of learning (behavioral, cognitive, and attitudinal), blended methodologies (quantitative, qualitative, and physiological measurement), and human performance improvement. The outcome of such eclectic research undertaking will not only inform all stakeholders about the effect of instructional games, but also will provide concurrent evidence, from various disciplines, to further our understanding on human learning.

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KEY TERMS

4C/ID-Model: 4C/ID-model is a non-linear and systematic processing model for designing complex learning environment based on cognitive load theory. The model consists of learning tasks, supportive information, part-task practices, and just-in-time information. The design focus of this model is on the integration and coordination of various levels of intended problem-solving skills. As a result, learners are able to transfer desired performance to various contexts with efficiency.

Cognitive Load: The amount of mental effort learners invest during the learning process. Which is also closely associated with learner' working memory capacity. The purpose of instructional design is to optimize the allocation of cognitive load to induce the deep learning process.

Extraneous Cognitive Load: This type of cognitive load only associates with the searching and organization of information, which should occupy the least amount of working memory. Instructional designers should utilize multimedia and other cognitive-oriented design to reduce the extraneous cognitive load.

Game: A game is a context in which individual or teamed players, bounded by rules, compete in attaining identified game objectives.

Germane Cognitive Load: This type of cognitive load is directly associated with the construction of schema. Instructional designers should aim to increase the level of germane cognitive load, induced by the instruction, as much as possible.

Intrinsic Cognitive Load: This cognitive load is inherent with the difficulty of the subject matter (e.g., organic chemistry versus multiplication). The cognitive load level cannot be manipulated by instructional design.

Schema: A schema is a memory unit stored in learners' long-term memory. Schema consists of mental models for reasoning and cognitive strategies for problem-solving.