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Problem-Based Learning *is* Compatible with Human Cognitive Architecture: Commentary on Kirschner, Sweller, and Clark (2006)

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Kirschner, Sweller, and Clark (2006) suggest that unguided or minimally guided instructional approaches are less effective and efficient for novices than guided instructional approaches because they ignore the structures that constitute human cognitive architecture. While we concur with the authors on this point, we do not agree to their equation of problem-based learning with minimally guided instruction. In this commentary, we argue that problem-based learning is an instructional approach that allows for flexible adaptation of guidance, and that, contrary to Kirschner et al.'s conclusions, its underlying principles are very well compatible with the manner in which our cognitive structures are organized.

In a recent article, Kirschner, Sweller, and Clark (2006) assert that unguided or minimally guided instructional approaches are less effective and efficient than guided instructional approaches because they ignore the structures that constitute human cognitive architecture. While we concur with the authors about the failure of minimally guided instruction for novices learning in structured domains, in this commentary we will argue that problem-based learning (PBL) is an instructional approach that cannot be equated with minimally guided instruction. On the contrary, we contend that the elements of PBL allow for flexible adaptation of guidance, making this instructional approach potentially more compatible with the manner in which our cognitive structures are organized than the direct guided instructional approach advocated by Kirschner et al. (2006).

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Note, though, that PBL is an instructional system containing a number of central elements that may nonetheless be implemented in a variety of ways (Barrows, 1986; Dochy, Segers, Van den Bossche, & Gijbels, 2003; Lloyd-Jones, Margetson, & Bligh, 1998). We will describe the elements of PBL and their cognitive basis and show how they can be and are being used in contemporary PBL curricula to align the instruction with the structures that constitute human cognitive architecture. More specifically, we present the multiple ways in which intrinsic, extraneous, and germane cognitive load can be managed through these elements.

DESCRIPTION OF THE PBL APPROACH AND ITS RATIONALE

Since its development in medical education in the mid-1960s, PBL has been developed and implemented in an increasing number of other subject-matter domains such as business, education, psychology, economics, architecture, law, engineering, social work, and even secondary education (Barrows, 1996).

PBL can be characterized as follows: A collection of carefully constructed "problems" is presented to small groups of students. These problems usually consist of a description of observable phenomena or events that are to be understood in terms of their underlying theoretical explanation. They are sometimes derived from professional practice (as is the case with problem-based medical education); more often they comprise the phenomena to-be-explained central to a particular domain of study. An example of such a problem, derived from an introductory course in psychology[1] is the following problem:

Little Monsters

"Coming home from work, tired and in need of a hot bath, Anita, an account manager, discovers two spiders in her tub. She shrinks back, screams, and runs away. Her heart pounds, a cold sweat is coming over her. A neighbor saves her from her difficult situation by killing the little animals using a newspaper."

Explain what has happened here.

During initial discussion, the task of the group is to construct a tentative theory explaining the phenomena described, based on prior knowledge, and expressed in terms of some underlying process, principle, or mechanism. Since students' prior knowledge is limited, questions will come up and dilemmas will arise that are used as learning issues for subsequent, individual learning. Usually, the groups meet twice a week for two or three hours. Between sessions, students spend considerable time on independent learning, studying sources of information relevant to the problem at hand.[2] Students are free to choose their own resources (although, as will be shown below, the search component can be reduced by offering a restricted set of resources or by tutor suggestions) and are encouraged to study for meaning, if possible using more than one source for each of the issues identified. During a second session, time is spent on critical appraisal of the knowledge acquired. Students try to find out whether their understanding of the problem has deepened as a result of the learning activities. Different perspectives on the problem (if any) are reflected upon, and students elaborate upon difficult topics. While working on a problem, the group is guided by a tutor. His or her task is to stimulate the discussion, to provide students—if necessary—with just-in-time subject-matter information, to evaluate progress being made, and to monitor the extent to which each group member contributes to the group's work. In summary, PBL is an attempt to create a learning environment for students enabling them to (a) learn in the context of meaningful problems, (b) actively construct mental models that help in understanding these problems, using prior knowledge, (c) learn through sharing cognitions about these problems with peers, and (d) develop self-directed learning skills (Norman & Schmidt, 1992).

In terms of cognitive architecture, two processes are considered crucial to PBL: Activation of prior knowledge and elaboration (Schmidt, 1993). The assumption is that initial problem discussion helps students activate whatever knowledge, formal or informal, they may have about the problem. This knowledge, in turn, will facilitate the comprehension of information subsequently processed. Since the problems are tailored to the level of the students, even novices will have knowledge that may help them understanding new information. These assumptions were tested in a study by Schmidt, De Grave, De Volder, Moust, and Patel (1989). They presented small groups of fourteen-year old high school students with the following problem:

What a pity!

"A red blood cell is put in pure water under a microscope. The cell swells and eventually bursts. Another blood cell is added to an aqueous salt solution. It shrinks."

Explain these phenomena.

These students had never heard of the subject concerned (which was the biological process of osmosis). Therefore, their explanations mainly had a common-sense character. In an attempt to account for the swelling of the blood cell, one group assumed that the membrane probably had "valves," which would let the water in, but would prevent it from escaping again. A second group maintained that the cell must be filled with tiny sponges absorbing the water. A third group explained the shrinking of the cell by assuming that salt has hygroscopic characteristics. According to them, the salt "soaked up" fluids from the cell in the way that it would with a wine-stained table cloth. Half of the students discussed the blood-cell problem, while the other half discussed an unrelated problem. Subsequently, all participants studied the same six-page text about osmosis. The group that had discussed the blood-cell problem prior to reading the text remembered significantly (in fact 40%) more about the text than the group that had discussed the unrelated problem but studied the same text. This finding indicates that activation of prior knowledge through problem discussion in a small group definitely facilitates understanding and remembering new information, even if that prior knowledge is only to a small extent relevant for understanding the problem—and sometimes even

[1] The problem is part of a first-year course of the problem-based psychology curriculum at Erasmus University, The Netherlands.

[2] In the "Little Monsters" example, the issues studied by students were (a) the nature of phobic fear; (b) the role of classical and operant conditioning in fear development; (c) alternatives to Pavlovian and Skinnerian conceptualization of conditioning; (d) the biological basis of the stress response (sweating; pounding heart); and (e) treatment procedures for phobic fear.

incorrect. Interestingly, more advanced students who studied the topic of osmosis a few weeks before the experiment was conducted (called the "experts" by the authors) did not gain as much from the experimental treatment as the novices (here the relative learning gain was 11%), suggesting that problem discussion is most helpful if students have only limited knowledge of the subject. The PBL process aims to increase the interaction between knowledge already available in the learners and the new, to-be-learned information; elaboration by (self-)explanations during group discussions stimulates the integration of new information into the knowledge base already present in long-term memory (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Pressley et al., 1992).

EFFECTIVE LEARNING ACCORDING TO COGNITIVE LOAD THEORY (CLT)

CLT's central notion is that for effective learning to commence, the architecture of the learner's cognitive system, the learning environment, and interactions between both must be understood, accommodated, and aligned (Sweller, 1988, 1999). For novice learners, who lack proper schemas to integrate the new information with their prior knowledge, CLT suggests that the free exploration of a highly complex environment may generate a heavy working memory load that is detrimental to learning (Paas, Renkl, & Sweller, 2003). Indeed, much of the research of Sweller and colleagues (including two of the present authors) have shown that for individual learning in (mostly) structured domains, formats of guided instruction, such as worked examples are more effective in the initial phases of cognitive skill acquisition than the unguided format of solving the equivalent problems (i.e., the worked-example effect; for an overview see Atkinson, Derry, Renkl, & Wortham, 2001).

CLT distinguishes between three categories of cognitive load: intrinsic, extraneous, and germane. *Intrinsic load* is determined by the degree to which the elements of the to-be-learned information can, or cannot, be understood in isolation (i.e., element interactivity). For instance, learning a foreign language vocabulary is a low-element interactive task, because most of the words can be learned in isolation to all of the other words. Learning a foreign language grammar, however, is a high-element interactive task, because many elements must be considered simultaneously (e.g., all of the words in a sentence, syntax, and tense). The load imposed by the number of elements a learner has to attend to simultaneously to understand the learning material is influenced by the learner's prior knowledge or expertise. As a consequence of learning through schema construction and automation intrinsic load is reduced with increasing knowledge or expertise: What are numerous elements for a low-expertise learner may be only one or a few elements (i.e., chunks) for a high-expertise learner. CLT assumes that intrinsic load cannot be directly influenced by instructional manipulations, only simpler versions of the learning task that omit some interacting elements can be used to reduce this type of cognitive load.

Besides the task-related intrinsic load, the manner in which the task information is presented to learners and the learning activities required of learners impose an instructional-design-related extrinsic cognitive load. If that load is ineffective for learning, it is referred to as *extraneous cognitive load;* if it is effective for learning, it is called *germane cognitive load*. This latter type of load is imposed by activities that are believed to foster the learning process. CLT recommends instructional designers to use germane load inducing methods, such as self-explaining (Chi et al., 1989; Pressley et al., 1992), with relatively simple tasks, in which the simultaneous processing of all interacting information elements leaves some spare cognitive capacity (Paas et al., 2003). With relatively complex tasks CLT recommends to use germane load inducing methods in combination with methods that decrease the intrinsic cognitive load (Van Merriënboer, Kester, & Paas, 2006).

COMPATIBILITY OF PBL WITH COGNITIVE ARCHITECTURE CONCEPTIONS

One of the basic tenets of PBL can be summarized as scaffolding for student independence. Kirschner et al. (2006), however, seem to confuse the ultimate goal of student independence with novice learners being unguided or minimally guided in PBL. Just like CLT, PBL approaches are strongly influenced by cognitive psychology and based on Atkinson and Shiffrin's (1968) sensory-memory–working-memory–long-term-memory model. In the next paragraphs we will demonstrate that PBL, like CLT, can incorporate extensive guidance structures that can be flexibly adapted to the level of learner expertise and the complexity of the learning task.

PBL curricula comprise the following elements: (a) Students are assembled in *small groups*; (b) these groups receive *training in group collaboration skills* prior to the instruction; (c) their *learning task* is to explain phenomena described in the problem in terms of its underlying principles or mechanism; (d) they do this by initially discussing the problem at hand, *activating* whatever *prior knowledge* is available to each of them; (e) a *tutor* is present to facilitate the learning; (f) (s)he does this by using a *tutor instruction* consisting of relevant information, questions, etc., provided by the problem designer; and (g) *resources* for self-directed study by the students such as books, articles, or other media. Although the exact implementation of these elements may differ between curricula (Lloyd-Jones et al., 1998), which, as Dochy et al. (2003) point out, is the case with every instructional approach (e.g., there is not a single form of "conventional" lecture-based curricula), these elements can be and are being used to provide guidance in alignment with students' cognitive architecture. In terms of CLT, these elements of PBL are used to optimize the relationships between the intrinsic load imposed by the task and the extrinsic load imposed by the instruction. The latter type of load is called extraneous load if it interferes with learning and germane load if it fosters learning. Next we will discuss how the elements of PBL can be used to manage cognitive load.

Training Group Collaboration Skills

When an instructional technique or technology is used that is in itself unfamiliar, it is important to train students in it before instruction starts, in order to reduce the additional extraneous cognitive load that engaging in this technique or with this technology would bring along (cf. Clarke, Ayres, & Sweller, 2005). Therefore, in order to minimize the extraneous cognitive load associated with the communication and coordination of knowledge between the group members, students in a PBL curriculum will typically be trained in group collaboration skills before instruction starts. This training focuses on (a) mastering of a standard procedure to translate problems into learning issues for individual study and (b) structuring of the group communication process by learning the various roles required for optimum group performance. At the Erasmus University Rotterdam, for example, students are trained in a systematic, seven-step procedure to analyze a problem at hand and to "translate" this problem into a set of learning issues for individual study. The first step is the clarification of terms and concepts in the problem text that are not easily understood. For the red blood cell example above, some students might not know the meaning of the word "aqueous" for instance. In the second step, a definition of the problem is generated: What exactly is in need of explanation? Students generate questions such as "Why does the first red blood cell burst, while the other one shrinks?" The third step is the brainstorm. Students raise ideas, hypotheses, and questions about the problem, based on their prior knowledge and elaborations through group discussion. With respect to the red-blood-cell problem, students come up with ideas about characteristics of the cell's membrane as described above. Furthermore, they rise possibilities for the swelling (e.g., a red blood cell carries oxygen and withdraws oxygen from the water which causes the swelling), bursting (e.g., blood cells usually take in small amounts of liquids, because there are many in the body. In this case, there is only one cell that has to take in too much water), and shrinking (e.g., in salt the cell dries up). Possibly, they search for analogies such as balloons inflated up to bursting or bodies floating in the sea. The various explanations that are produced in the brainstorm are subsequently systematized and scrutinized in view of the information available, which is the fourth step. In our example, different explanations for swelling as well as the other processes are clustered and discussed more in-depth. The questions that came to the fore during the third and fourth steps form the issues for individual learning, and a list of these issues is the product of the fifth step. "How does osmosis work and which processes are involved?" could be a learning issue for the blood-cell problem. In sixth step the learning issues guide students' individual study activities, in which students study the available resources (i.e., book chapters, articles, Internet sites, relevant movie clips, animations, etc.). During the seventh step, the students share findings, review and critically discuss the literature, solve remaining problems, and synthesize what is learned. This seven-step procedure helps students to simplify the learning situation and makes more predictable what is required from them.

In addition, students are trained in the various facilitative roles that have to be played in the tutorial group. They are in particular trained to play the role of the chairperson and of the scribe. The chairperson chairs the discussions; (s)he summarizes and concludes. In addition, the chairperson has to take care that the seven-step procedure is followed. The scribe keeps track of the main hypotheses, learning issues, and conclusions by writing them down on a blackboard, so that a log of all ideas that were brought up is available for later scrutiny. All these activities are geared toward minimizing extraneous load in CLT parlance.

Learning Tasks

In the design of problem-based instruction, simple-to-complex whole task sequences are used such that students start with the easiest problem and progressively proceed to more complex or expert-like problems. For instance, students in a problem-based medical course on the cardiovascular system would work on problems of circulation before they would be confronted with problems of malfunctioning of the cardiovascular system. This simple-to-complex sequence makes optimal use of the reduction of intrinsic load with increasing expertise, allowing students to acquire knowledge in the simpler tasks that reappear in the more complex tasks along with new information, stimulating elaboration. However, since PBL is based on "authentic" problems, for learners with no prior knowledge even the learning tasks in the simple categories are characterized by a high amount of interacting information elements (i.e., high intrinsic load).

Tutorial Groups

Human cognitive architecture, and in particular the limitations of working memory capacity at the individual level (Cowan, 2001), is an important reason to assign learning tasks to groups rather than to individuals. It is believed that the more complex the task (i.e., the higher the intrinsic cognitive load), the more efficient it will become for individuals to cooperate with other individuals in a fashion that this load is shared (Ohtsubo, 2005). Here, the group discussion plays an important role.

Group Discussion

The group discussion in PBL is intended to reach two goals: *Activating* whatever prior knowledge is available among individuals to deal with the task and *sharing* expertise. The assumption is that by activating and sharing prior knowledge among group members, intrinsic cognitive load decreases, thereby decreasing the necessity of omitting interacting elements and enabling students to deal with more complex tasks. Support for the notion of the activating and sharing function of small-group discussion was found in an experiment referred to in Schmidt (1993). Groups of students in a health sciences curriculum were presented with the blood-cell problem described earlier or an unrelated problem. A few hours prior to the experiment, all of the students involved had been acquainted with the subject of osmosis, which is the underlying explanatory mechanism for the phenomena described in the problem. No additional text was studied in the experiment. In a free-recall test, the group that had discussed the blood-cell problem remembered almost twice as much about osmosis as the other group. This demonstrates that problem analysis in a small group indeed has a strong activating effect on prior knowledge (see also Pressley et al., 1992). Since activation of prior knowledge has been shown to facilitate the processing of new knowledge, we argue that this occurs because it decreases the load intrinsic to the task.

It should be noted that PBL differs from most other approaches to group-based instruction in that the problem comes first and that students are initially engaged in problem discussion using—and thereby activating—only their own prior knowledge. Most other methods employing small-group discussion either have students study information individually before they discuss a problem or teach them information online (e.g., Cohen, 1994; Slavin, 1996).

Tutor

If a learning task, despite being carefully designed and having been discussed in the group, turns out to be too complex or if an essential knowledge element for the group's learning process was not activated during discussion, the tutor is instructed to share this knowledge with the group, thereby reducing intrinsic load. In line with CLT claims that the advantage of guidance begins to recede only when learners have sufficiently high prior knowledge, research has shown that tutor effectiveness depends on tutor subject-matter expertise, prior knowledge of the student, and the amount of structure present in the instruction. For example, Schmidt (1994) found that subject-matter expertise of tutors mattered most in courses in which prior knowledge of students was low or when instruction was structured poorly. In order to reduce extraneous load, the tutor is instructed to prevent students from spending too much time on irrelevant information or dead ends. When students are ready for it, the tutor can try to induce a germane load by challenging students to allocate cognitive resources to cognitive activities that will contribute to learning, such as providing self-explanations or reflecting on (their input in) the group discussion. The tutors also receive a tutor instruction in the form of a booklet that they can consult to gear the goals of the learning task to the group's problem discussion process.

Resources for Individual Learning

Searching for literature and other resources is considered an important constituent skill that is mastered by successful professionals. However, successfully searching for literature is highly dependent on domain knowledge. Hence, novice learners are likely to engage in irrelevant literature search activities, which impose a high extraneous load. Therefore, novice students in PBL are provided with a restricted set of resources (e.g., book chapters, articles) to choose from for individual study. With increasing expertise students are provided with less and less specified resources to stimulate them to search for relevant literature themselves.

CONCLUSION

We have argued that Kirschner et al.'s (2006) classification of PBL as unguided or minimally guided instruction is incorrect. We have substantiated our claim by describing how the elements that comprise PBL allow for flexible adaptation of guidance and management of cognitive load, thereby showing that PBL is compatible with the manner in which our cognitive structures are organized.

Apart from our main focus in this commentary on the compatibility of PBL with cognitive architecture, there are some other remarks to be made that may invalidate Kirschner et al.'s (2006) comparison of effectiveness of PBL with effectiveness of guided instruction. First, the evidence they report in favor of guided instruction comes mostly from highly structured domains, using problems that can indeed be called complex in terms of CLT (i.e., a high number of interactive elements in a task), but are quite simple when complexity is defined in terms of the possibility of multiple solution paths or even multiple solutions (see Campbell, 1988). Since the problems used in PBL are usually complex in terms of the second definition, this comparison is not entirely fair. In addition, the evidence in favor of guided instruction comes from studies on individual learning settings instead of group-based learning settings such as PBL, where different cognitive load conditions apply. One should therefore be careful not to apply instructional design guidelines for individual learning directly to group-based learning settings.

Second, the evidence they report to the detriment of PBL in medical education falls short. While citing some of the curricular comparison studies (which generally do not show differential effects of PBL on knowledge acquisition), they fail to mention the extensive criticisms that these studies evoked (e.g., Albanese, 2000; Norman & Schmidt, 2000). Norman and Schmidt (2000), for instance, argue that comparisons between instructional interventions at the curriculum level are doomed to fail because randomization of students over the treatment conditions is almost always impossible, and, since medical students are highly selected in terms of knowledge and skill required to enter medical school, performance on achievement tests are bound to show ceiling effects, leaving little room for improvement. Moreover, Kirschner et al. (2006) fail to mention a recent review by Dochy et al. (2003), reporting robust advantages of PBL over conventional instruction with regard to the students' ability to apply knowledge (i.e., skills). Finally, they do not refer to the *experimental* studies available in the literature that, as we have demonstrated above, are most pertinent to the issues they raise. These experiments show that discussion of a problem prior to processing new information strongly facilitates the comprehension of that information attesting to the effectiveness of PBL (e.g., Capon & Kuhn, 2004; De Grave, Schmidt, & Boshuizen, 2001; Schmidt et al., 1989).

A third and last problem in comparing the effectiveness of PBL and guided instruction is the following: Whereas many conventional curricula are focused on the acquisition and *direct* application of knowledge, PBL is more focused on the *flexible* application of knowledge. In terms of type of knowledge and type of transfer ability assessed, PBL focuses more on knowledge about how to interpret and approach problems (i.e., interpretive knowledge; see Schwartz, Bransford, & Sears, 2005). As a consequence, the kind of transfer that is aimed at includes the ability to prepare for future learning, for example, the ability to define what information one needs to be able to solve a problem. In contrast, many forms of guided instruction tend to focus more on directly applicable knowledge and focus on "sequestered problem solving" transfer tasks that require learners to solve problems based on the acquired knowledge, without the option of seeking out additional information (Schwartz et al., 2005). Consequently, the outcome of comparison studies depends on the type of assessment used. The central role of assessment is underlined in a recent meta-analysis on PBL by Gijbels, Dochy, Van den Bossche, and Segers (2005). This study demonstrated that effects of PBL differed according to the levels of the knowledge structure that were measured with various types of exams measuring different types of knowledge structure levels. PBL had the most positive effects when the focal constructs being assessed were at the level of understanding principles that link concepts.

In conclusion, PBL involves many of the principles relevant to CLT and is *not* an example of minimally guided instruction when it is implemented with the proper degree of scaffolding as we described. We hope, therefore, that our commentary will inspire collaborative research of the PBL and CLT research communities, for instance, to investigate how CLT could be used to further exploit the potential of PBL or how PBL could be used to extend CLT with group-based cognitive load issues.

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