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CONCEPT MAPPING INFORMED BY COGNITIVE LOAD THEORY: IMPLICATIONS FOR TASKS INVOLVING LEARNER-GENERATED CMAPS

Paulo Rogério Miranda Correia & Joana Guilares de Aguiar, Universidade de São Paulo, Brazil
Email: prmc@usp.br, www.mapasconceituais.com.br

Abstract. Cognitive load theory (CLT) presents principles that serve as guidelines to improve instructional design. CLT foundations are based on a model of human cognitive architecture that assumes an unlimited long-term memory (LTM) and a limited working memory (WM). This cognitive approach aligns with Ausubel's learning theory but also explains in more detail the role of instructional design (e.g., selection of study materials and organization of the learning tasks) to understand how we construct and automatize schemas. Concept maps (Cmaps) have been widely recognized as a graphical organizer that can foster meaningful learning. However, the cognitive overload caused by tasks involving learner-generated Cmaps has rarely been discussed. Beyond processing the learning content (intrinsic cognitive load) the Cmap elaboration (extraneous cognitive load) must be simultaneously handled by the WM. All this cognitive demand (intrinsic + extraneous cognitive loads) might surpass the learners' WM resources. The cognitive overload caused by the learner-generated Cmap task hinders meaningful learning. This paper brings new theoretical insights from CLT to discuss the critical role of training novice users to fully understand the central concepts of concept mapping (proposition, focus question, recursive revision, and hierarchy). We advocate the need to improve the instructional design of training methods to reduce the extraneous cognitive load caused by learner-generated Cmap tasks, avoiding the cognitive overload. CLT explains why the lack of effective training on concept mapping produces the naïve Cmaps usually obtained in everyday classrooms.

Keywords: Cognitive Load Theory, Cognitive Overload, Concept Mapping, Instructional Design, Training Methods.

1 Concept mapping in everyday classrooms: A closer look at some challenges

Concept maps (Cmaps) are graphic organizers used to represent mappers' knowledge structures. They were first proposed by Novak and colleagues in the 1970s (Novak, 2010). The propositional structure of Cmaps (initial concept – linking phrase → final concept), which asks for the inclusion of linking phrases to clarify conceptual relationships, makes concept mapping more powerful than other graphical techniques used to represent knowledge and information (Correia, 2012; Davies, 2011). The use of Cmaps in everyday classrooms and e-learning environments depends on a sound understanding of the theoretical foundations of this technique. The difficulty of representing mental structures in map-like diagrams (e.g., Cmaps) is frequently overlooked in the literature (Zumbach, 2009). The ease of using programs such as CmapTools is confounded by the demanding task of selecting concepts and propositions to create good Cmaps (Aguiar et al., 2014; Aguiar & Correia, 2013; Cañas et al., 2014; Cañas & Novak, 2006). In other words, concept mapping is a cognitively demanding task to produce a diagram that resembles the mapper's mental structures about a specific learning content.

Research on concept mapping applied to learning suggests that tasks involving learner-generated Cmaps can support meaningful learning based on the following aspects:

- Cmaps encourage students to engage in productive activities fostering active learning (de Jong, 2010; Klahr & Nigam, 2004; Mayer, 2004).
- Cmaps can reflect students' understanding of the learning content (Shavelson et al., 2005).
- Concept mapping promotes deeper information processing during Cmap elaboration (Nesbit & Adesope, 2006).
- Cmaps enable teachers to assess and correct a learner's misconceptions, fostering the pedagogic resonance (Kinchin et al., 2008; Novak, 2002).

The critical condition for achieving these benefits is knowing how to create good Cmaps - namely, Cmaps presenting propositions with clear semantic meanings that reflect the mappers' understanding of the learning content. In other words, the Cmaps (external knowledge representation) must be related to the mappers' mental models (internal knowledge representations).

Some papers in the literature highlight that Cmap construction requires extensive training (Aguiar et al., 2014; Aguiar & Correia, 2013; Conradty & Bogner, 2010; Correia et al., 2008; Hilbert & Renkl, 2008; Karpicke & Blunt, 2011). This is a cognitively demanding process (Hall & Blair, 1993) and requires significant intervention on the part of the instructor to guide novices who struggle with this unfamiliar technique and the conceptual content to be mapped (Robinson et al., 2003). Moreover, Cmaps are content-specific visualization tools; in other words, it is not possible to learn how to use them without specific content to be mapped. The cognitive load of creating good Cmaps is higher than most teachers can imagine because the student needs to carry out two simultaneous processes:

- Understand and apply the rules of how to make a Cmap; and
- Understand the topic to be mapped to select concepts and propositions to organize the Cmap.

Learning in complex domains such as mathematics, computer programming, and science is typically constrained by the working memory's (WM) limited cognitive processing capacity. For novices, learning tasks in these domains typically represent situations near the limit of their WM resources. The association of content complexity and cognitive processes to solve the task at hand (e.g., mapping the conceptual relationships about a topic under study) can surpass the WM resources and cause cognitive overload. In such a situation, the learning process (construction and automation of new conceptual schemas) is impaired (Sweller et al., 2011). Cognitive load theory (CLT) offers relevant inputs to understand and describe why learner-generated Cmaps might hinder meaningful learning. In other words, we can use CLT theoretical background to set up an explanation about why the lack of effective training on concept mapping produces naïve Cmaps usually obtained in everyday classrooms.

Figure 1 summarizes a cycle of events that occurs in everyday classrooms when Cmaps are used without planning for and understanding of this technique of knowledge representation. Teachers' lack of theoretical background, methodological planning, and practical knowledge in concept mapping can lead to the following undesirable sequence of events.

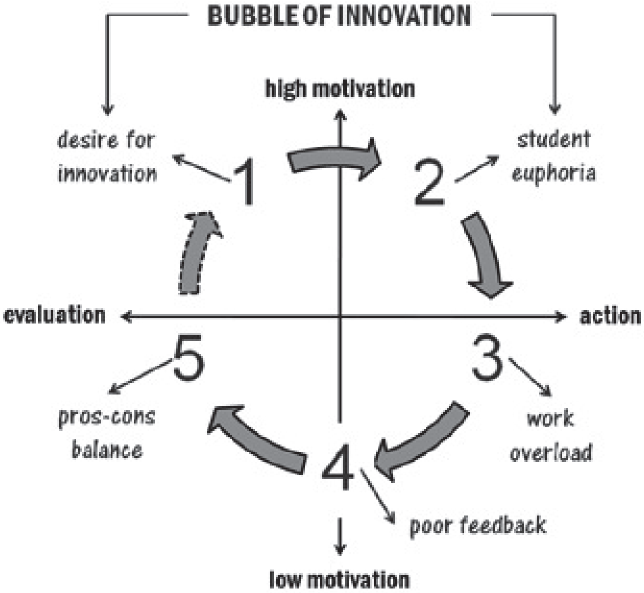

Figure 1. Why are everyday classrooms resistant to change? A five-event cycle describes our hypothesis, considering reflective practice (x-axis) and motivation (y-axis) as the main variables. The "innovation bubble" is an analogy to economic bubbles, characterized by high expectations associated with poor fundamentals to justify them.

1) Desire for innovation: the teacher uses Cmaps to change the classroom routine.
2) Student euphoria: the students produce many Cmaps in a short period of time (few classes) because they are fascinated with the new classroom climate.
3) Work overload: the teacher has difficulty handling the large amount of Cmaps because the textbook does not provide an appropriate grading method.
4) Poor feedback: the teacher stops providing feedback to the students creating Cmaps, and evaluation is restricted to a simple verification of their production.
5) Pros-cons balance: the teacher does not realize all the benefits of concept mapping, makes unfavorable judgments about it, and avoids future use.

The main goal of this paper is to use the CLT perspective to analyze the learner-generated Cmap process in different situations, considering (i) the level of understanding of the concept mapping technique and (ii) the level of understanding of the topic to be mapped. Our rationale can illuminate some discussions involving the instructional design of concept mapping activities to be adopted in classroom or e-learning environments.

2 New inputs from the cognitive load theory

CLT was initially developed in the 1980s from strictly controlled experimental studies (e.g., Sweller, 1988; Sweller & Cooper, 1985). CLT is concerned with the manner with which cognitive resources are used during learning through problem solving. This theory generates some instructional design principles to optimize the limited WM cognitive resources in order to improve learners' ability to use acquired knowledge and skills in new situations. All these instructional principles are based on the human cognitive architecture and the cognitive load management required to boost the creation and automation of new conceptual schemas.

2.1 Working memory and long-term memory: Different properties and functions

CLT assumes a limited short-term memory (i.e., WM) that can hold no more than five to nine information elements. It is able to deal with this amount of information for no more than a few seconds, and almost all information is lost after about 20 seconds. WM is limited in capacity when dealing with completely new information (i.e., concepts and propositions from a new subject) because, as the number of elements that need to be organized increases linearly, the number of possible combinations of elements that must be tested for effectiveness during problem solving increases exponentially (Sweller et al., 2011).

New concepts and propositions must be chunked and stored in the long-term memory (LTM) to ensure the schema construction and automation. The schema construction can be achieved through the incorporation of new elements in schemas already available in LTM or by obtaining already schematized information from experts. Schemas can then be treated as a single element in WM when they are well-known and automatized, significantly reducing the cognitive load imposed on WM. Constructed schemas can become automated if they are repeatedly applied and yield the desired results. Because automation requires a great deal of practice, well-designed instruction should not only encourage schema construction, but also support schema automation for those aspects that are consistent across tasks (Sweller et al., 2011).

In parallel with Ausubel's assimilation theory (Ausubel, 2000), schema construction refers to the manner of novel information is incorporated in previous cognitive structure and might be held in LTM. Schema automation can be understood as meaningful learning - that is, when learners are able to use relevant knowledge as a single element to solve new problems different than those used during the learning process.

2.2 Cognitive loads imposed on the WM during the learning process

The CLT distinguishes three types of cognitive loads capable of interfering in the WM's processing information and consequently with the learning outcomes (Sweller et al., 2011):

- **Intrinsic load:** refers to the nature, complexity, and difficulty of the content with which learners must deal during the learning task. For example, reading a list of concepts imposes less intrinsic load than reading a Cmap. Whereas the first task involves several single and disconnected elements (low element interactivity), the second task needs to understand the connections among the concepts embedded into a propositional network (high element interactivity).
- **Extraneous load**: refers to the nature of the instructional design used to present the learning material or task. For example, there are several ways to address the meaning of a *square*. One could be to present a verbal or textual description of vertical and horizontal lines that meet in 90° angles. Another way is to present plenty of images of diverse squares and, in the end, a short definition of it. Despite dealing with the same concept, the first instructional option will increase the level of extraneous load and possibly affect the learning process.
- **Germane load**: refers to the WM resources devoted to the schema creation, from the conceptual manipulation of the information presented through the instructional material. During the learning task, students must engage in highly demanding cognitive processes, such as analysis, classification, organization, and inference.

These cognitive loads are different ontological categories related to the learning content (intrinsic), instructional material/task selected by the teacher (extraneous), and cognitive processes used to learn (germane). Intrinsic and extraneous cognitive loads are additive and must be managed to avoid overload. This condition is critical for making WM cognitive resources available to process information and learn (germane). Figure 2 represents how instructional planning can be used to avoid cognitive overload by reducing intrinsic load, extraneous load, or both.

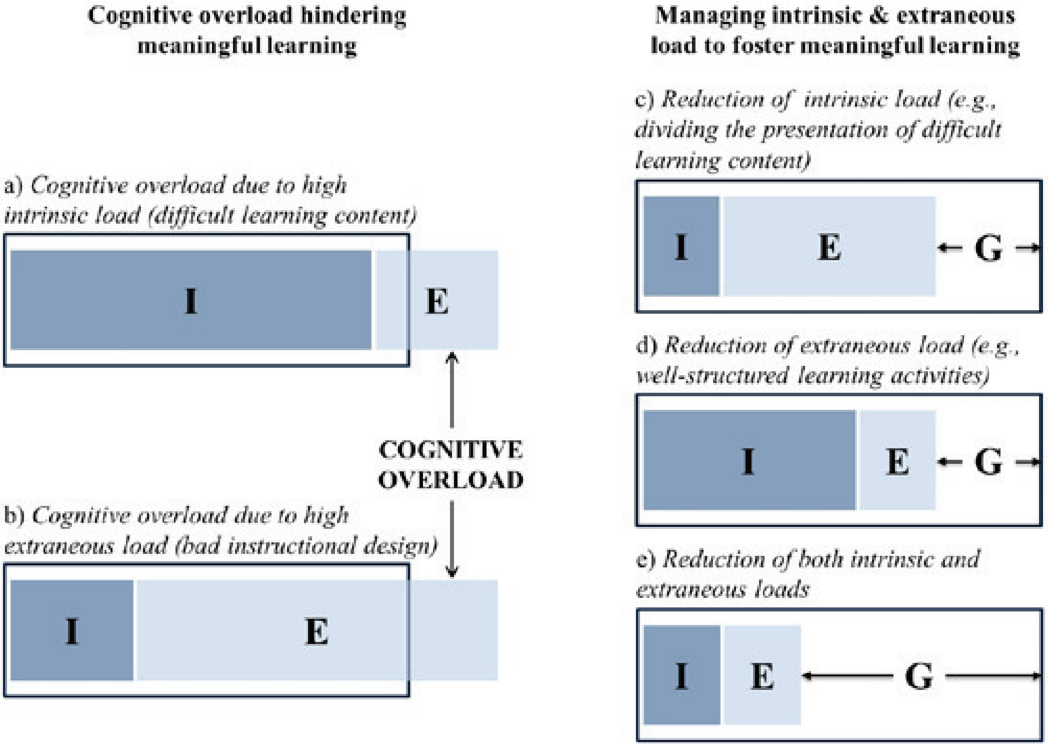

Figure 2. Additive feature of intrinsic (I, blue) and extraneous (E, light blue) loads imposed on the WM cognitive resources (rectangle). Cognitive overload can be reached due to high (a) intrinsic load or (b) extraneous load. The overload condition can be avoided by reducing (c) intrinsic load, (d) extraneous load, or (e) both. Germane load (G) only appears when there is no overload of WM (c–e).

The sum of intrinsic (I) and extraneous (E) loads can surpass the WM cognitive resources (Figure 2a-2b). This cognitive overload hinders meaningful learning because there is no resource available to germane (G) processes (creation and automation of new conceptual schemas) take place. The management of I and E loads is critical for liberating WM resources to G processes (van Merriënboer & Sweller, 2010). We can reduce I, E, and both loads (Figure 2c-2e). The I load cannot be altered by instructional interventions without changing the topic to be learned (e.g., simplification of the learning task by dividing the topic into several classes). Simple contents have low element interactivity requiring less WM resources once the concepts can be learned in isolation (Figure 2c). As a result, fewer WM resources are needed to handle the I load, and G processes can take place during the learning process. This condition is likely to produce meaningful learning.

Figure 2d shows the E load reduction due to a well-planned learning task. Ill-structured instructional designs impose a high E load, especially when learners must use weak problem-solving methods that require them to arbitrarily try out things without being given proper guidance or scaffolding. Learners use the most WM resources to deal with the instructional materials and/or learning tasks. One goal of instructional design is to reduce the E load (Sweller et al., 2011). The selection of instructional materials and the design of the learning tasks are teachers' responsibility, and they can apply any of several principles derived from CLT (van Merriënboer & Sweller, 2010). The reduction of the E load using suitable instructional design can avoid cognitive overload, and G processes can take place during the learning process. This condition is likely to produce meaningful learning. Finally, Figure 2e shows a similar effect when I and E loads are reduced to make WM resources available to G processes.

3 Cognitive loads of tasks involving learner-generated Cmaps

Learner-generated Cmaps are the products of highly cognitive demanding tasks. They can be analyzed considering the loads (I, E, and G) proposed by CLT (Figure 3). Two key variables are used to determine the existence (or not) of cognitive overload: (i) learners' prior knowledge of the content to be mapped and (ii) learners' prior knowledge of the concept mapping technique. These variables affect the I and E loads, respectively, and must be taken into account to avoid WM cognitive overload.

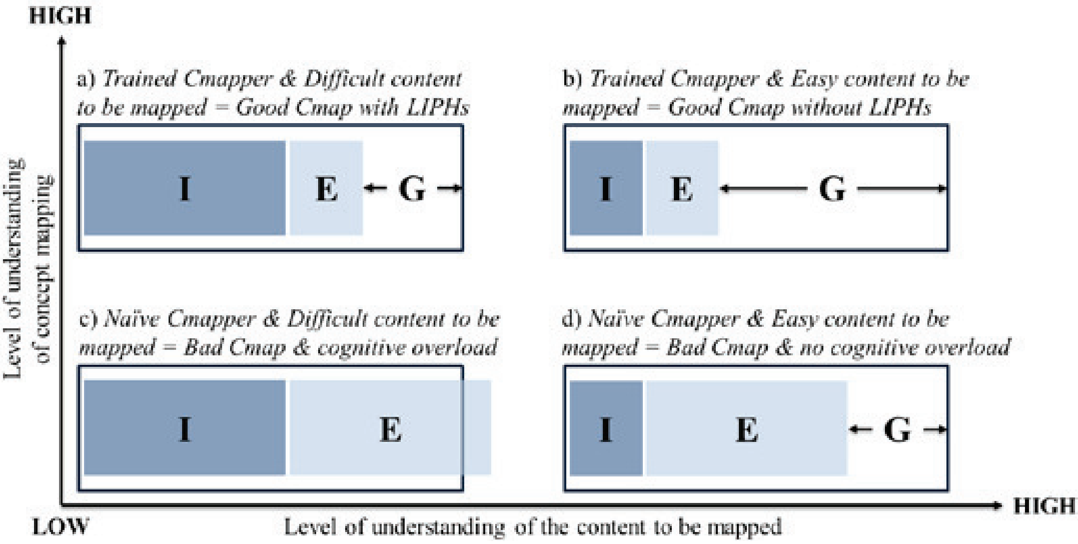

Figure 3. Four conditions considering the analysis of learner-generated Cmap tasks using the learners' level of understanding of the content to be mapped (I, x- axis) and the concept mapping technique (E, y-axis). Trained Cmappers are likely to produce good Cmaps (a–b) whereas naïve Cmappers are likely to produce bad Cmaps (c–d), even when there is no cognitive overload (d).

Training learners to become skilled Cmappers reduces the E load (Figure 3a-3b) because the ability to make Cmaps is directly related to the design of the learning task. In this case, learners can always produce good Cmaps related to their knowledge. Cmaps about difficult topics (Figure 3a) might present some errors or conceptual limitations. As Novak suggested, meaningful learning can be fostered from the limited or inappropriate propositional hierarchies (LIPHs) that allow teachers to provide precise feedback considering the specific conceptual gaps revealed in the Cmaps (Novak, 2002). On the other hand, Cmaps about easy topics (Figure 3b) are likely to be good without LIPHs.

Naïve Cmappers who do not receive training on how to create good Cmaps face a higher E load (Figure 3c-3d). They do not know how to produce good Cmaps, and the outcome is likely to be bad Cmaps with no or unclear propositions. Bad Cmaps do not reveal the mappers' knowledge structure appropriately and are not related with the internal knowledge representation (mental models). Bad Cmaps are obtained for both difficult (Figure 3c) and easy (Figure 3d) topics. Even knowing the content (easy topic), naïve Cmappers cannot express their understanding through concept mapping; in such cases, it is better to ask them to write a text to assess their knowledge of the content to be learned. No cognitive overload occurs in this condition (Figure 3d), and the level of understanding of concept mapping is the unique variable that hinders the creation of good Cmaps. The critical role of training novice users using a well-designed set of activities becomes clear with this rationale, which is why our research group devoted time and resources to developing a set of strategies to improve the skills of students on concept mapping (Aguiar et al., 2014; Aguiar & Correia, 2013; Correia et al., 2008). We argue that more than a few minutes is needed to train students appropriately to become good Cmappers.

Cognitive overload appears only when naïve Cmappers need to map a difficult topic (Figure 3c). We believe this condition might represent the use of concept mapping in many everyday classrooms. The poor training of students is associated with ill-structured activities involving Cmaps. This combination helps explain the innovation bubble presented in Figure 1. Students are stuck in a context that does not allow for the creation of good Cmaps. Therefore, the expected benefits related to fostering meaningful learning will not be achieved. Teachers and students will make unfavorable judgments about concept mapping and will abandon the use of Cmaps. In sum, naïve mappers (Figures 3c-3d) can explain why we obtain bad Cmaps in many activities we develop in everyday classrooms. Thus, the critical role of training students to become trained Cmappers is highlighted once again.

4 How to design a task involving learner-generated Cmaps

The task for the elaboration of Cmaps impacts their content and structure. Cañas et al. (2012) highlighted this effect of task configuration on students' Cmaps using a graph to organize typical Cmap tasks into a continuum from total freedom to total restriction of content and structure (Figure 4). This approach provides an insightful connection between instructional design and learning outcomes (students' Cmaps).

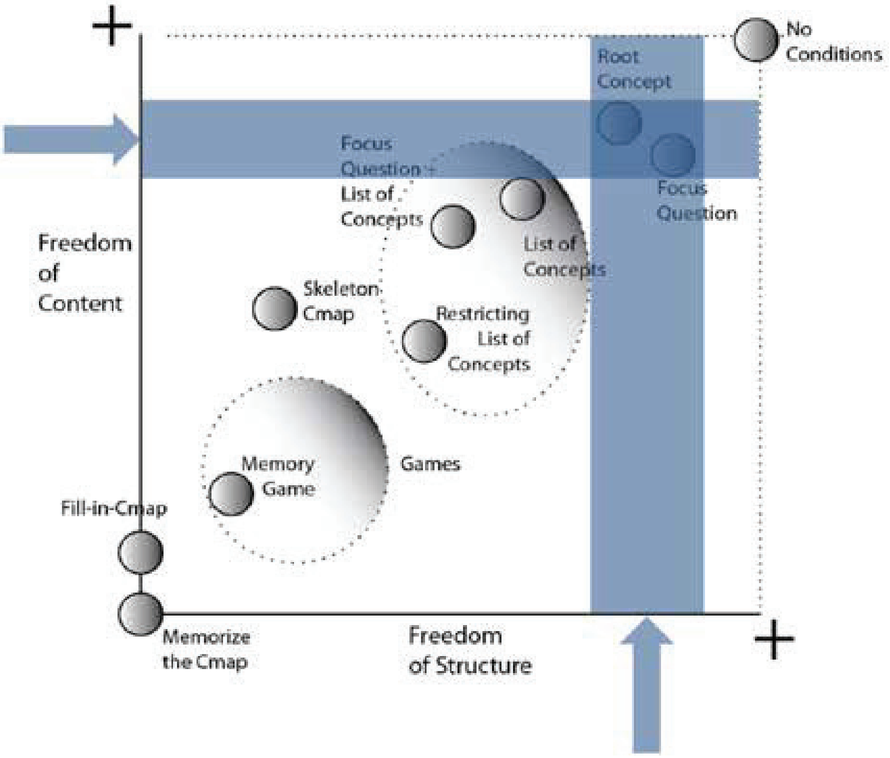

Figure 4. Freedom of structure and content conditions to describe concept mapping task. The instruction to elaborate Cmaps can vary from total freedom (no conditions) to total restriction (memorize the Cmap), which affects students' Cmap (Cañas et al., 2012). Blue columns highlight our preffered option to set up a task involving learner-generated Cmaps. The E load is reduced when a root concept and a focus question are provided.

The maximum degree of freedom (no conditions) is more appropriate for experts in concept mapping and the topic to be mapped. They can use WM resources to model their knowledge using Cmaps because they do not need to create and automatize conceptual schemas. Experts already have these schemas and are easily manipulated in WM (these chunks of information impose low cognitive loads). On the other hand, trained Cmappers who are learning about a topic can face a high E load when facing too much freedom. Despite knowing how to use the concept mapping technique, they need to deal with content that is not in well-organized conceptual schemas. The I load is high in this situation, and we need to design a task involving learner-generated Cmaps that lower the E load. Providing a root concept and a focus question are two strategies our research group usually adopts to (i) get a set of comparable Cmaps and (ii) reduce the E load of the task. This information calls students' attention to key parts of the topic under study and activates their knowledge while considering these cues. The cognitive effort to make a Cmap in this condition is mainly related to the I load and G processes to manipulate the conceptual schemas they already have. Frequently produced Cmaps reveal learners' LIPHs; in this condition, concept mapping can be more valuable in everyday classrooms. Pedagogic resonance is possible, and the collaboration between teachers and students can happen in favorable conditions because learners' knowledge is visible (Kinchin et al., 2008). Teachers can provide specific and powerful feedback to remediate misconceptions and foster meaningful learning during their courses.

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