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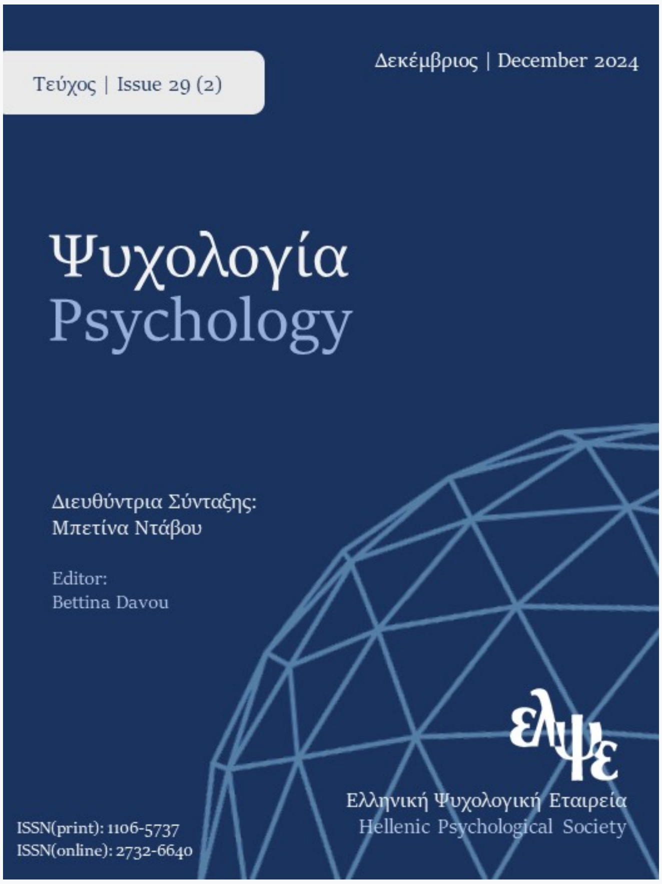

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Rethinking Engagement: Insights from conceptual change research

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ABSTRACT

Current research in the field of cognitive developmental psychology has highlighted a componential approach to engagement, involving at least three key components that co-occur during learning, an emotional, a behavioral and a cognitive one. At the same time, there is little agreement on the internal key components that occur during engagement and how they interact. In the present paper we will try to address this issue in the light of a particular kind of learning, conceptual change learning. More specifically, we will illustrate, based on research data, how internal factors, such as students' prior knowledge and their epistemic beliefs, along with external factors, such as cultural tools, can influence students' momentary engagement with science content, especially when there is a need for re-organization of their intuitive theories, thereby leading to conceptual change. We will focus on how these factors can support learning, but at the same time can set obstacles to staying momentarily engaged in the classroom in the case of conceptual change learning. Finally, we will discuss how understanding momentary engagement in the context of conceptual change can enhance our understanding of how to moderate the rate or success of conceptual change as well as the appropriate types of learning environments that are necessary to achieve this goal.

Introduction

Research has highlighted a componential perspective of students' engagement, i.e., students' active participation in learning activities, referring to engagement as a broad multidimensional construct, including and interacting with at least three key elements, an emotional, a behavioral and a cognitive one (Archambault, 2009; Fredricks et al., 2004; Sinatra et al., 2015; Skinner et al., 2008). According to this dominant premise, each component undoubtedly co-occurs with the other components during learning.

The *emotional* component refers to students' affective reactions when they face an academic task that may activate or deactivate engagement (e.g., enthusiasm, interest, enjoyment, satisfaction, etc. vs. boredom, frustration, sadness, anxiety, etc.) (Skinner et al., 2008). Having a sense that they belong to the school or that they value it highly is included in the emotional component. Research supports that students are more likely to actively engage in schoolwork, when they recognize the personal and practical value of school (Voelkl, 2012). The *behavioral* component refers to students' effort and persistence during the initiation and execution of a task and includes actions such as attendance and participation in learning tasks (attention, concentration,

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involvement, intensity, etc., vs. passivity, withdrawal, distraction, etc.) (Fredricks et al., 2004; Skinner et al., 2008). The *cognitive* component refers to how students use surface or deep-processing strategies and self-regulation strategies, as well as to their willingness to engage in cognitively challenging activities (Cleary & Zimmerman, 2012; Sinatra et al., 2015). Recently, researchers introduced a new element of engagement; that is, *agentic* engagement. This dimension of engagement occurs when students contribute to the flow of engagement by enriching and personalizing instruction, i.e., a student-initiated pathway to the creation of a supportive learning environment where students claim their learning preferences, express their level of interest, communicate what they already know and what they need to learn, and set their goals (Reeve, 2013; Reeve & Tseng, 2011; Sinatra et al., 2015).

However, there is little agreement on both the key components of student engagement and, more importantly, on their interrelations. In a recent paper, Symonds and colleagues (2021) discuss these interrelations and focus on student's momentary engagement, which is located particularly at the micro-level and encompasses an individual student's interaction with a learning task (e.g., learning about genetically modified food) across short-time intervals (e.g., across seconds or minutes), at the moment. Momentary engagement differs from other forms of engagement that occur at the macro-level, such as when larger student groups are involved in more complex activities (e.g., schoolwork) over an extended period, such as a school year. The authors apply the Dynamic Systems approach (DS), borrowed by developmental psychology, to momentary engagement indicating that we can conceptualize engagement as a complex dynamic developmental system concerning its structure and dynamics changing from moment-to-moment in order to adapt to a continuously changing situation (Lewis, 2011). According to DS approach, behavior arises from complex interactions among various factors operating at different levels and across diverse time scales. Behavioral patterns manifest on a moment-to-moment basis, stemming from the interactions among the elements of the system via a process of self-organization (Siegler & Alibali, 2020). In accordance with this approach, Symonds et al. (2021) argue that momentary engagement can only be understood as a unified system, indicating that it is the integration of the emotional, cognitive, and behavioral components into a whole that leads to the manifestation of engagement in a dynamic way across time. Referring to the co-actions between engagement and its components, the authors further discuss both conscious and unconscious self-organization of the system, with bottom-up and top-down control processes working together to maintain engagement. This complex system changes dynamically across time as being a non-linear one. As they pose it, "momentary engagement is individual involvement in an activity that proceeds through complex non-linear psychological and behavioral dynamics occurring across seconds and minutes" (Symonds et al., 2021, p.17).

In addition to more domain-general aspects of engagement (e.g., attention, metacognition, emotions, or psychophysiological arousal) that can be seen in any content area and may lead to a behavioral, cognitive, or emotional response, researchers have also moved on to discuss whether domain-specific aspects of engagement, i.e., aspects that interact with specific content area, should be worth keeping in mind. Sinatra and colleagues contend that several factors (e.g., epistemic cognition, misconceptions, topic emotions, attitudes, involvement in scientific practices, etc.) may impact student engagement in the science domain differently than in other domains (Sinatra et al., 2015). The above mentioned question --whether these domain-specific aspects of engagement are important-- must be reconsidered within the context of a more specific kind of science learning; that is conceptual change type of learning. The simplest type of conceptual change involves enrichment-learning mechanisms of our existing conceptual structures, i.e. the addition of new information to our existing theoretical frameworks. But what happens when new information is counter-intuitive to our prior knowledge, therefore enrichment-learning mechanisms are insufficient and instead a strong knowledge restructuring is needed? Conceptual change of this type refers to significant changes that occur in our conceptual structures after exposure to counter-intuitive concepts. These changes require the development of new modes of knowing (i.e., reorganization of the existing knowledge structures) and new ways of reasoning. They constitute a slow and gradual process involving the emergence of ontological, epistemological, and representational changes (Vosniadou, 2008, 2013, 2017; Vosniadou et al., 2008). How domain-specific aspects like epistemic beliefs or prior knowledge and misconceptions impact student's engagement with science content, particularly student's momentary engagement with science content, i.e., student's activity at the micro-level of agent, task, and time?

In conceptual change research tradition, various domain-specific factors have been identified as being important; internal factors, such as interest, prior knowledge and confidence in prior knowledge, self-efficacy, epistemic beliefs, and external factors, such as tools, models, and cultural artifacts, which may play a complex, dual role in conceptual change learning as opposed to traditional knowledge acquisition (Cordova et al., 2014; Dole & Sinatra, 1998; Linnenbrink & Pintrich, 2002; Mason et al., 2008). This paper will focus on how some of these internal and external domain-specific factors can affect students' momentary engagement with science content, particularly with content that relates to the observational astronomy domain, especially when re-organization of students' intuitive theories is needed, and can drive conceptual change.

Specifically, we will examine three domain-specific factors: (a) prior knowledge, (b) epistemic beliefs, and (c) cultural artifacts, i.e., culturally accepted psychological or physical tools that may carry scientific knowledge, can be internalized and may influence --guide and even control-- thinking and reasoning. Our discussion will focus on how these factors may support learning but, at the same time, may stand as barriers for students to staying momentarily engaged in the classroom, especially in the case of conceptual change learning.

We will present data from the conceptual change research tradition to examine how the qualities of these factors may vary in this specific type of learning. Lastly, we will discuss how the understanding of momentary engagement in the case of conceptual change will help us progress our knowledge on how we can moderate the rate or success of conceptual change and on the kind of learning environments that we need in order to achieve this.

Conceptualizing conceptual change: The Framework Theory Approach

A recent constructivist approach to Conceptual Change, based on the results of research in cognitive developmental psychology, is the *Framework Theory Approach* (Vosniadou, 2017, 2012; Vosniadou & Skopeliti, 2014; Vosniadou et al., 2008). A framework theory is a skeletal conceptual structure that underlies people's deepest ontological commitments and provides a means of understanding the world (Vosniadou, 2017). Various framework theories can exist, such as a framework theory of physics, psychology, or biology (Wellman & Gelman, 1998). Developmental research has demonstrated that infants begin to categorize and form ontological distinctions based on their everyday experiences within cultural contexts.

A framework theory is not an unchanging theory but a flexible yet coherent explanatory system that evolves as new information comes in. Because scientific theories are distinct from the framework theories, learning science requires numerous conceptual changes, including changes in categorization, representations, and personal epistemologies, and the creation of new concepts and reasoning processes. These are intricate conceptual changes and do not occur overnight. From this perspective, this approach does not depict faulty and rigid naïve theories but rather a dynamic conceptual system comprising various elements organized in complex ways. Therefore, conceptual change is not simply about replacing one theory with another, as in the classical approach by Posner et al., (1982); instead, it appears to be a slow and gradual process that entails the creation of new ontological categories within the context of continuous representational and epistemological sophistication (Vosniadou, 2017).

For example, during the preschool years, children appear to develop an initial concept of the earth based on their interpretations of everyday experiences and cultural information, all within the constraints of a naïve framework theory of physics (Vosniadou & Brewer, 1992; Vosniadou & Skopeliti, 2014). More specifically, children seem to begin by categorizing the earth as a physical object rather than as an astronomical one, primarily because they struggle to understand its autonomous movement. Thus, they apply to it all the presuppositions that typically pertain to physical objects in general. The assumption that children operate under the constraints of initial ontological and epistemological presuppositions can explain the formation of these initial models that depict the earth as a flat, supported, and stable physical object with the sky and solar objects located above it. The scientific concept of the earth that children encounter in school violates all the presuppositions that apply to this initial earth concept.

As noted above, a framework theory is a constructivist approach that assumes that students employ constructive learning mechanisms to link new information with their existing knowledge base. However, things get more complicated when the new scientific concepts are incongruent with the pre-existing knowledge base. In such cases, children assimilate scientific explanations to what they already know and generate synthetic conceptions or models. For example, the model of the “dual earth” represents a synthetic model that effectively resolves the conflict between the flat and spherical earth models without abandoning any of the presuppositions inherent to the framework theory. Within this model, children refer to another earth, a planet situated “up in the sky,” rather than the flat, supported ground on which people live (Vosniadou, 1994).

The presence of these synthetic conceptions holds significance within this theoretical approach, not because it suggests that students always exhibit coherence, but rather because it illustrates that even very young children are sensitive to issues of coherence and empirical adequacy of explanation. By the end of elementary school, most children appear to have developed the concept of a spherical earth as an astronomical object floating in the sky and surrounded by space and solar objects (Vosniadou, 1994).

Domain-specific aspects of engagement: Influences on conceptual change learning

As Sinatra and colleagues (2015) argue, domain-specific factors may impact engagement differently in science than in other domains. In the case of conceptual change, achieving high levels of engagement with the material and employing in-depth cognitive processes are required (Linnenbrink & Pintrich, 2002). We will focus on the following factors: (a) prior knowledge, (b) epistemic beliefs, and (c) culturally accepted artifacts and we will examine their impact on students’ engagement and momentary engagement during knowledge revision processes in the observational astronomy domain. More specifically, we will examine how these specific factors determine one’s choice to engage during a task or learning activity and discuss how the qualities of these factors may vary in this conceptual change type of learning.

The impact of prior knowledge

> Experimenter: If you walked and walked for many days, where would you end up?
> Child: If we walked for a very long time, we might end up at the end of the earth.
> E: Would you ever reach the edge of the earth?
> C: I don’t think so.
> E: Say we just kept walking and walking, and we had plenty of food with us.
> C: Probably.
> E: Could you fall off the edge of the earth?
> C: No. Because if we were outside of the earth, we could probably fall off, but if we were inside the earth, we couldn’t fall off.

(Vosniadou & Brewer, 1992, p.548)

In Vosniadou and Brewer's research, Mathew, a first grader, seems to have knowledge about the spherical shape of the earth. However, although he argues that the earth is round on the outside, he believes that the earth is flat inside and that people live on this flat ground. How can this apparent inconsistency in Mathew's thinking be explained? In what ways do Mathew's prior knowledge interfere with and influence his engagement in this task?

Research has shown that prior knowledge has an important impact on learning engagement and constitutes a critical factor (Dong et al., 2020; Rodrigues, 2007). Indeed, the existing knowledge base seems to be one of the most important factors that affect subsequent learning in an explicit or implicit way (Dochy et al., 2002). However, is prior knowledge always beneficial? Returning to the previous example, it seems that Mathew's prior knowledge, i.e., what he perceives in everyday life, with people standing on flat ground, is in conflict with what he learns at school, i.e., that the earth is a sphere and people live all around it. In this case, Mathew's initial theory about the physical world and his existing presupposition that unsupported things fall, interfere, and shape the way he thinks about and filters the new information to be learned. The paradox in this case is that prior knowledge is both a barrier to change and a means for change because it must be revised. At the same time, new conflicting information is integrated into children's existing explanatory frameworks (Mayer, 2002; Pintrich et al., 1993).

Another important aspect to consider is that most of the time, this controversy between prior and new conceptions may not be within the learner's awareness. Students may engage in conceptual change without a deliberate, purposeful intent. Evidence indicating this lack of intentional learning is the presence of inconsistencies when students are unaware of the conflicts within their existing knowledge base. Studies have revealed that when children encounter scientific explanations, they shift from their initial representations to the scientific one without consciously recognizing this change. However, the coherence of their initial framework may disintegrate as their initial theory is replaced by a mixture of unconnected explanations linked to specific contexts of use, with some grounded on the initial theory and others on the scientific one (Ioannides & Vosniadou, 2002).

An illustrating example comes from the Vosniadou, Skopeliti, and Ikospentaki study (2005). In the first part of the study, participants, comprising first and fifth-grade students, replied to an open-ended questionnaire about the shape of the earth, and in the second part, they had to respond to the same questions in the presence of a globe. The following example comes from a first grader who initially argued that the earth is flat. In what follows, there are the questions and responses after the globe was introduced.

> Experimenter: If you walked for many days, where would you end up?
> Child: I would go back to where I started.
> E: Is there an end/edge to the earth?
> C: Yes, there is.
> E: Can you fall from this end/edge?
> C: Yes, it is in the bottom part of the earth and you cannot stand there.
> E: Can people live down here at the South Pole?
> C: (the child looks at the bottom part of the globe to see if there is a country there) Yes, there is a country there.
> E: Just before you told me that people cannot live down there.
> C: No, they do (looks again at the South Pole to make sure).
> E: Finally, what is the real shape of the earth?
> C: Finally, it is like the globe.
> E: Where do the people live?
> C: Finally, the people live everywhere.
>
> (Vosniadou et al., 2005, p.346)

In the first part of the questionnaire, the child argued that the earth is flat. However, in the second part, she adopted the spherical earth model, but at the same time, she showed inconsistency in her responses, providing answers that were either based on a spherical representation or on a flat representation of the earth. Following that, the child had to claim whether she had changed her original response. Along with 23 out of 33 students who changed their initial responses, this specific child claimed that she had not made any changes. The results revealed that 73% of the participants changed their original responses in the presence of the globe without being aware of this change. Thus, the presentation of the globe poses the scientific presuppositions about the shape of the earth leading students to adopt the scientific information. However, conceptual change learning driven by intentional learning was not immediate, as internal inconsistencies in participants' responses increased, and those who changed their initial responses were unaware of this change.

For this reason, for conceptual change to occur, students need to be encouraged to think about conflicting views and question their existing theoretical frameworks. It is therefore necessary for students to be aware that the new information they are learning is incompatible with their prior conceptions in order to restructure their naïve theories. According to Pintrich and colleagues (1993), "a student would undergo an unfreezing of his or her cognition in order to seek specific cognitive closure-that is, the resolution of the discrepancy" (Pintrich et al., 1993, p. 192). In this direction, simple exposure to a scientific text may not be a catalytic factor, and it seems that this instructional method does not consider the complex and constructive nature of children's misconceptions. Indeed, students who read a scientific text incongruent with their prior knowledge created new misconceptions (Vosniadou & Skopeliti, 2017).

According to Vosniadou and Skopeliti (2017), children's prior knowledge influenced the way they engaged with the text and did not support the creation of a situation model of the text. As a result, children ignored the scientific information or generated invalid inferences, even though these were more advanced compared to their initial explanations indicating positive incremental changes in their prior knowledge. For example, there were numerous cases where students initially gave responses consistent with a naïve intuitive explanation of the day/night cycle ("The Sun goes behind the clouds and the mountains and does not shine anymore. The Moon takes the Sun's place and starts to shine.") and constructed a drawing consistent with this explanation, showing the sun moving behind mountains and the moon rising in the sky. After being exposed to a text that presented scientific information, many students changed their initial verbal explanations and showed positive changes. However, their explanations showed that in most cases, the participants did not construct a consistent situation model; instead, they revealed internal inconsistencies. A common verbal explanation found in the results included two incompatible ideas ("In order to get dark, the Earth turns and the Sun moves to the other side and then it changes to day."), and was accompanied by a drawing identical to the one constructed initially, showing the sun moving behind mountains and the moon coming up in the sky (Vosniadou & Skopeliti, 2017, p. 2043). Thus, it seems that providing expository science texts hinders deep engagement and retrospection of alternative views and instead induces superficial engagement with scientific concepts (Mason et al., 2008).

How can we alert children to their existing frameworks and foster in-depth engagement? As discussed before, using expository science texts may not be the better instructional method and may not lead children to the type of engagement needed for conceptual change. What type of conceptual change interventions may facilitate children to become aware of their misconceptions and move toward their revision? Several researchers investigated the effects of conceptual change mechanisms, i.e., the effects of analogy-enriched texts and refutation texts on the learning of a scientific explanation (Mason & Gava, 2007; Mason et al., 2008).

Refutation texts have been found to produce better conceptual change learning outcomes, bridging children's prior knowledge with scientific explanation. This type of text fosters children's engagement with their own beliefs, revealing the discrepancies, and urges them to reflect on their naïve frameworks (Diakidoy et al., 2016; Diakidoy et al., 2003; Kendeou & Van den Broek, 2007). The typical structure of a refutation text consists of the negation of a misconception and the presentation of the scientific explanation. Vosniadou & Skopeliti (2017) move on to propose that it may be even more beneficial to explicitly mention all the steps one must make in order to shift from a naïve belief to the understanding of a scientific idea. Texts that address children's naïve beliefs and provide critical explanations that help children to find the links between the scientific point of view and their prior knowledge (e.g., explain why we perceive the earth as flat when it is actually a sphere) could be more successful to persuade children and engage them in conceptual change learning (Vosniadou, 2001). Relevant research has also indicated that the use of categorical information in refutation texts (e.g., that the earth is an astronomical object rather than a physical object) improves children's comprehension (Skopeliti & Vosniadou, 2016). This is because categorical information is generic and includes important implicit information the reader can use to guide new learning. Students who read a refutation text with categorical information managed to improve their responses not only in explicit questions -the answers to which derived directly from the text- but also in inferential questions –the answers to which were concluded implicitly from the text (Skopeliti & Vosniadou, 2016, p. 463). It appears that introducing the categorical information also supported high engagement by leading students to "create a non-egocentric representation of the earth as a spherical planet in space" (p. 464).

Analogy-enriched texts are also valuable tools for teaching scientific concepts (Duit, 1991). An analogy may facilitate engagement in restructuring processes because it draws upon children's conceptions from a highly familiar domain to promote the understanding of an unfamiliar domain (Arabatzis et al., 2009). In a recent study, third and fifth graders read an analogy-enriched text explaining the day/night cycle (Vosniadou & Skopeliti, 2018). In this text, a "gyros" analogy was used. In Greece, gyros involves roasting a typically spherical or elliptical piece of meat on a vertical rotisserie that revolves around a fixed fire source. In this analogy, gyros represents the earth, as it rotates around its axis (the vertical rotisserie) in the presence of a stationary sun (fire). The rotation of the earth results in only one side of the earth being illuminated, analogous to the roasting process in the preparation of gyros. Even though only few of the participants fully understood and learned the scientific explanation for this physical phenomenon, the results showed that the analogy-enriched text produced more incremental positive changes in children's explanations compared to the no-analogy text. Most of the students in this study initially argued that the day/night cycle happens because the sun goes behind the mountains or because the sun revolves around the earth and constructed a drawing consistent with this explanation. Many students, after reading the analogy-enriched text, gave verbal explanations improved compared to the ones that they gave in the pretest (e.g., "The earth is rotating and that's how it changes from day to night."), while at the same time, they changed in a consistent manner their drawing. This finding implies that the analogy fostered participants' engagement by building on their perceptions from a familiar area and helped students construct a dynamic representation of the scientific explanation, which they used in order to create their drawings (Vosniadou & Skopeliti, 2018, p. 746).

Similar studies have shown that students who read texts with analogies are more likely to engage in restructuring processes and not simply add new, scientific information to their pre-existing knowledge base (Skopeliti et al., 2009; Vosniadou et al., 2007). In this study, adults showed engagement in depth while reading a text with an instructional analogy that explained the change of seasons. The analogy drew upon the structural similarity between the way sun's rays hit the earth throughout the day and the way sun's rays hit the surface of the earth throughout a year (moon-summer and early morning-winter). The great majority of the participants (70%) changed in a consistent manner their initial explanations after reading the analogy text. This was not the case for the participants who read a no-analogy text since most of them either did not change their initial responses (40%) or they moved to an inconsistent change (20%); namely, they changed their verbal explanation, but did not change their drawing to be in agreement with their verbal explanations (Skopeliti et al., 2009, p. 430). Thus, it seems that learning from texts that do not use students' prior knowledge in a constructive way, like refutation texts or analogy-enriched texts do, may result in only superficial students' engagement, and the learning mechanisms are rather conservative. Simple expository scientific texts enable students only to add or delete pieces of information. However, this process may cause local inconsistencies in the knowledge base when there is a conflict between the new information and our prior knowledge. Refutation texts and analogy-enriched texts may support students' engagement in depth and play a positive role in the learning process in that they seem to support restructuring mechanisms and facilitate more global changes.

Lastly, we must also consider the different ways prior knowledge interacts with motivational and affective variables in conceptual change compared to traditional forms of learning. For example, although high prior knowledge (high familiarity with the topic and high basic understanding of the relevant concepts and vocabulary) and high interest may promote enrichment processes, they may also act as an obstacle to conceptual change, due to the strength of prior beliefs or to the high confidence in the existing framework, which may lead to higher commitment in a domain and to resistance to conceptual change (Dole & Sinatra, 1998; Linnenbrink-Garcia et al., 2012; Murphy et al., 2005; Pintrich et al.,1993). Similarly, although self-confidence has a positive impact on learning, self-confidence in the correctness of an idea limits deep engagement due to the unwillingness to change the idea (Cordova et al., 2014; Pintrich et al. 1993). Indeed, considering the learners' characteristics, Cordova and her colleagues (2014) found that a "mixed student's profile" (i.e, depicting high confidence, self-efficacy, and interest but low prior scientific understanding and high prior misconceptions) seemed to be more productive for a conceptual change compared to a "high student's profile" (i.e., depicting high confidence, self-efficacy, interest, and prior scientific understanding and low prior misconceptions).

The impact of epistemic beliefs

In a study conducted by Kyriakopoulou & Vosniadou (2020), two fifth graders, John and Mary, see two depictions of the day/night change. One depiction is in accordance with "how things appear to be" (i.e., the sun sets behind the mountains and the moon comes up to the sky), and the other is in accordance with "how things really are" (i.e., the earth rotates on its axis and around the sun). Children are asked to think about two types of questions: a) questions that test their understanding of the referential nature of these depictions -"Look at the two pictures. What does the first picture show? What does the second picture show?- and b) a question that tests whether these children are able to understand that the two pictures refer to the same phenomenon in the world- "What are the differences between these two pictures?" (Kyriakopoulou & Vosniadou, 2020, pp. 5-6).

In this example, both John and Mary had knowledge of the scientific explanation of the day-night change, but they ended up with totally different answers [unpublished data from Kyriakopoulou & Vosniadou, 2020]. Mary could locate the differences between the two representations, indicating that they both refer to the same phenomenon and seemed to manipulate them appropriately depending on the different contexts, i.e. discriminate which one refers to appearance and which one refers to reality. Although John had also solved the ontological problem and had constructed the scientific explanation, he thought that this scientific representation stood both for appearance and for reality. What led these children to engage differently with these same representations despite the fact that they both had prior knowledge of the day/night change? What acted as a barrier for John and as a facilitator for Mary? When the same children were asked about their beliefs regarding the nature of science and the process of knowing, Mary said that knowledge is uncertain because there can always be alternative explanations. She argued that there can be disagreements between scientists, and in this case, we must examine the quality and the strength of the evidence. On the opposite, John said that knowledge is certain; authorities know most things and are a warrant for truth. In this case, he argued that there cannot be any disagreements between scientists; there is only one truth and the only reason for the existence of different perspectives is little information or mistakes. Did these naïve epistemic beliefs limit

John's engagement during the task? If I believe there is only one-way things are, does it make sense to think about different perspectives?

The ability to construct and manipulate dual representations has been attributed to several factors, e.g., content knowledge, executive function, and language ability, but has also been linked to children's epistemic beliefs (Carey & Smith, 1993; Elder, 2002; Kuhn, 2011; Kyriakopoulou & Vosniadou, 2020). Research on conceptual change in science learning has shown that children need to move to a more constructivist epistemology of science to restructure their naïve theories. They must understand that knowledge is complex, actively constructed, critically evaluated and not transmitted and justified by the authority. They need also to understand that there are multiple perspectives and that sometimes appearance may deceive us. They also need to weigh alternative points of view, evaluate sources and quality of evidence, identify reliable processes for knowing, and reflect on their own learning (Chinn et al., 2011; Sinatra & Chinn, 2012).

Epistemic beliefs are often considered a lens through which students interpret new information, define and use strategies, and plan actions (Buehl & Alexander, 2005; Chinn et al., 2011; Muis et al., 2018). A belief in simple and certain knowledge discourages students from considering alternative views, thus limiting the potential for conceptual change. Learners with more naïve, unsophisticated epistemic beliefs --such as that knowledge is stable and fixed-- avoid ambiguity, are less interested in deep thinking, and seek definitive knowledge provided by the authority. The more demanding cognitive processes needed to promote change are more likely to occur in students who believe in the active construction of knowledge by the individual (Hofer & Pintrich, 1997; Mason & Boscolo, 2004; Sinatra, 2005). Research has shown that more sophisticated epistemic beliefs (i.e., belief in the complex structure of knowledge, its evolving nature and active construction, and the need for its empirical evaluation) may lead to active engagement and change and are positive predictors of students' achievement (Bråten & Ferguson, 2014; Bråten et al., 2014; Muis et al., 2015). Learners with such beliefs tend to seek new information, pose questions, and question their current ideas. Indeed, beliefs about the nature of knowledge and knowing may facilitate or constrain intentional conceptual change; personal epistemologies determine students' goal orientation to deliberately change their conceptions (Mason, 2002). As Mason (2002) argues, epistemic beliefs might be considered as dispositions that "act as resources or constraints on change conceptions in that they do or do not, lead to developing the intention of knowledge revision" (p.321). Only the more advanced epistemic beliefs seem to contribute to in-depth, self-regulated, and intentional engagement, which may result in conceptual change.

Previous research (Kyriakopoulou & Vosniadou, 2004, 2008; Vosniadou & Kyriakopoulou, 2006) has shown that children find it difficult to develop such an epistemological perspective. Elementary school children cannot easily consider their representations of the world as hypotheses that may be disconfirmed and are not capable of metaconceptual handling of their knowledge. As discussed before, when asked to distinguish between a phenomenal ("how things appear to be") and a scientific representation ("how things really are") of a physical astronomical phenomenon, young children could not understand that the same physical input may receive different interpretations, which are not simple interpretations of sensory evidence. Indeed, children with more naive epistemic beliefs did not have the cognitive flexibility to form dual representations, which they would use explicitly and consciously in different situations as appropriate (Vosniadou & Kyriakopoulou, 2006). Children who still believed in absolute and true knowledge, which is based on simple observations of the physical world, could not understand the differences between the alternative representations and could not distinguish between appearance and reality. For the majority of the astronomical phenomena investigated, many of the first and third graders and even some of the fifth graders gave erroneous responses. They either thought that the scientific depictions represented 'appearance' and the phenomenal depictions represented 'reality' or in some cases selected only scientific depictions and thought that they represented both 'appearance' and 'reality'.

Research has shown that students' ability to integrate the use of multiple representations during science learning is limited. Students often tend to focus on surface features, overlooking underlying mechanisms and may struggle to coordinate between different representations (Kozma, 2003; Seufert, 2003; Won et al., 2014). Furthermore, they may encounter challenges when moving accurately and flexibly across various levels of representations (Kozma, 2003; Pozo et al., 1999; Spada, 1994; Wiser & Smith, 2009). It seems that it is rather difficult for children to understand that a different point of view or explanation may exist and may be better than the one they hold at that time, indicating a more constructivist epistemology (Treagust et al., 2017).

How can we promote epistemic sophistication? Epistemic cognition refers to "how individuals think about what they know, what knowledge is, how it can be used and how they know" (Sandoval et al., 2016, p.418). Under this scope, it is important to determine what type of school instruction is needed to facilitate students to shape more sophisticated epistemic beliefs which in turn influence their engagement, attention, and ability to reflect on conflicting perspectives. Moreover, what type of trigger do we need to bring epistemic beliefs to the level of learner's awareness so that conceptual change is promoted?

Research has highlighted the importance of instruction oriented towards epistemic sophistication (Kyriakopoulou & Vosniadou, 2014). Curricula that are designed to promote and support students' thinking about epistemic issues, the use of epistemic tools that facilitate children to express their conceptual understanding, and learning environments that make epistemic goals for engagement with scientific work visible to them, all together contribute to children's developing epistemology (Kyriakopoulou & Vosniadou, 2011; Sandoval & Reisser, 2004; Smith et al., 2000).

Previous research indicates that both theory of mind (i.e., our knowledge about the social world and our ability to understand our and others' mental states such as intentions, desires, emotions and beliefs) and epistemic understanding promote the aspect of science learning that has to do with the ability to understand multiple perspectives (Kyriakopoulou & Vosniadou, 2022). The awareness in the social domain that people can have different beliefs, becomes the foundation that helps children understand the constructive nature of knowledge in general (Eisbach, 2004; Osterhaus et al., 2017). This awareness, in turn, facilitates understanding in the science domain. In an instructional study, 20 fifth graders received a seventeen-hour instruction during their school program (Kyriakopoulou & Vosniadou, 2014). Children were encouraged to think about different perspectives and to reflect on the uncertain and elusive nature of knowledge first in the social domain. At a second level, they counted on this understanding to explore their ideas about the nature of knowledge, to discuss scientific controversies, and reflect on various arguments. The results indicated that children who engaged in these reflective processes were better at recognizing and thinking about multiple perspectives in the domain of observational astronomy compared to children who only received regular instruction in astronomy as specified in the Greek National Curriculum.

The impact of cultural artifacts

Experimenter: If you walked for many days, where would you end up?
Child: To the places above the earth and below the earth.
E: Is there an end/edge to the earth?
C: Yes, at the top and bottom part.
E: Can you fall off this end? C: No, you cannot.
E: Why not? C: Because you are inside the earth.
E: Can people live down here, at the South Pole?
C: (looks to see if there is a country there) Yes, they can.
E: If this little girl stood here and held a ball in her hands, and the ball fell, in which direction would it fall?
C: It will fall far away, below the earth.
E: Finally, what is the real shape of the earth?

C: It is like a globe.
E: And where do the people live?
C: Everywhere on the earth, all around and also inside.

(Vosniadou et al., 2005, p. 344)

In this example, George, a third grader, responds to the experimenter's questions about the shape of the earth in accordance with a model of a hollow-sphere earth [people live on a flat surface inside a hollow sphere]. In this excerpt, George argues that there is a place where the earth ends and this is located above and below the earth, but people cannot reach these places because they are inside the earth. However, when the questions are posed on the basis of the globe, George adjusts his responses based on the cultural artifact. It appears that he acknowledges the culturally accepted artifact representing the earth, but produces an inconsistent pattern of responses. How did the socially accepted model of the earth affect his engagement in this task?

The situative perspective considers knowledge as distributed between the person and his/her environment, including artifacts, tools, and various objects as well as the communities we live in (Greeno et al., 1996). Interactive processes between people and between people and physical and technological systems are at the center of this perspective. Indeed, previous research has shown that children have sophisticated knowledge of cultural artifacts (e.g., the globe) and can use them successfully when reasoning about earth and gravity (Schoultz et al., 2001; Ivarsson et al., 2002). According to this view, we should expect George not having any problems understanding the scientific information about the shape of the earth and gravity, when the cultural artifact was present (Nobes et al., 2003; Siegal et al., 2004). But is this the case?

Undoubtedly the presence of an artifact, like the globe, may facilitate George to think about the earth, because it communicates the presupposition of a spherical earth. However, although he can recognize a scientific fact, -people live at the bottom of the earth because there is a country there- when more generative questions are postulated, the answers to which do not derive directly from the artifact, he gets confused -if a ball fell off the hands of a little girl who stood at the bottom of the earth it would go far away below the earth. He ends up with a fragmented model of the earth, arguing that the earth is like the globe and that people live all around the earth as well as inside the earth.

This example shows the difficulties children may have when they are presented with an artifact, without taking into account their prior knowledge. Students are highly engaged in the process of learning when using a cultural artifact like the globe, although it is not always certain that this high engagement will lead to learning in cases when naïve prior knowledge interferes in the process. Skopeliti and Vosniadou (2007) claim that because children do not internalize an external representation passively, but through a process of simple and direct transmission, the information from the culture may be distorted, and misinterpretations may be generated. This constitutes a constructive process through which prior knowledge interferes with the external information.

Another factor that interferes in this process is the content of the cultural artifact presented to the students. Research data have shown that students interpret differently two alternative cultural artifacts representing the earth; the globe and the map. First and third graders were asked questions about the shape of the earth. Then, the flat-earthers were shown the globe and were asked to justify how come the earth appears to be spherical in the globe, while they said it is flat, and if they continue to believe that the earth is flat. The spherical-earthers were shown the map and were asked to explain how come the earth appears to be flat in the map while they said it is round, and if they continue to think that the earth is spherical. The majority of the flat-earthers (about 60% from both age groups) accepted the globe as a more representative model of the earth and tried to adjust their responses to the spherical model. On the contrary, all the spherical-earthers from both age groups argued that the map is just a mean to represent all different countries and none of them changed his/her original responses to be consistent with the flat model (Skopeliti & Vosniadou, 2007, p. 246). Thus, it appears that although children may be highly engaged during the use of cultural artifacts, the learning results that arise through this process are not the same, since students filter the artifacts based on their prior knowledge and do not accept them passively regardless of their content.

Thus, it appears that the use of cultural artifacts does not constitute "direct cultural transmission" (as exemplified in studies like Nobes et al., 2003, Nobes et al., 2005 or Schoultz et al., 2001). Instead, it represents a constructive process, during which the content of the cultural artifact is interpreted in the light of what the child already knows. Possibly, the information is distorted to be consistent with the child's prior knowledge (Vosniadou et al., 2004; 2005).

How can we effectively use the cultural artifacts? The purpose of the previous discussion is not to state that we should avoid using artifacts in science teaching practice. Instead, we must think about how we can bring them into educational practice, taking into account the constrains prior knowledge poses on them. Indeed, artifacts that contradict children's prior knowledge may give rise to cognitive conflict, not with the perspective to prove that prior knowledge is wrong, but in order to facilitate children's awareness of the gap between their prior beliefs and the culturally accepted scientific explanation (Vosniadou, 2019). This highlights the need to help students understand that their intuitive beliefs are based on an egocentric perspective and do not have the explanatory power to reason based on artifacts like the globe.

From the individual to the individual-in-context (and vice versa?)

Sinatra and colleagues (2015) contend that while the multidimensional view of engagement is valuable, researchers can further enhance this view by considering engagement instrumentation along a continuum. They argue that defining the level of granularity for conceptualizing and measuring engagement is critical, as this continuum ranges from the micro-level (individual-centered, momentary, and task-specific) to the macro-level (context-centered, encompassing group of learners, school, community) (Azevedo, 2015; Sinatra et al., 2015). According to this approach, at one end of the spectrum lies the individual, where behavioral, cognitive and emotional dimensions characterize engagement. At the opposite end, the focus shifts towards a more holistic, contextualized perspective. The features of the context, whether it is the classroom, school, community or culture, can either hinder or foster engagement. In the middle of the continuum lies the person-in-context. The focus centers on the individual situated within a specific context, particularly on the interaction between the individual and others (such as students with their peers) and the various dimensions of the learning environment.

A thorough discussion of the more holistic, situated social perspectives associated with the one end of this continuum falls outside the scope of this paper. Thus far, our discussion has revolved around engagement concerning the individual, with the primary unit of analysis being the individual and the task at hand. As Symonds and her colleagues claim, defining engagement at the micro-level (i.e., momentary engagement) helps us to understand the emergence of broader patterns of behavior from momentary experiences (Symonds et al., 2021). However, it is essential to also consider engagement from both an individual and a social perspective as both offer valuable insights into the process of learning (Anderson et. al, 2000).

What specific overt patterns of an individual behavior should we focus on when it comes to conceptual change learning? For instance, a student might display behavioral engagement through observable actions, like pointing, underlying, and manipulating objects. However, is this type of engagement alone sufficient for facilitating conceptual change, or is strong cognitive and metacognitive engagement also necessary? Conceptual change learning requires the learner to go beyond the presented material, to actively engage in the creation of new knowledge through constructive and generative processes. These processes include drawing analogies and concept-maps, formulating hypotheses, engaging in self-explanation and self-regulation, and more (Chi & Wylie, 2014).

Within this constructive mode of engagement, necessary for conceptual change learning, the primary focus remains on the individual. However, the process of conceptual change can be significantly enriched through a more interactive mode of engagement between individuals, which entails a constructive mode of engagement. In this sense, both partners must initially infer new knowledge and then engage in co-inference. This collaborative process allows for discussions, reflections and the enhancement of each other's understanding in an ongoing cyclical manner. Through these continuous interactions, individuals benefit from their partners' inferences, incorporating these insights along with their contributions and inferences (Chi & Wylie, 2014; Vosniadou et al., 2023).

Thus, the question previously raised can be reframed as follows: What specific overt patterns of social behavior should we emphasize when considering conceptual change learning? What modes of engagement become evident through the interactive shared dialogues for each participant? What role do social interactions play in shaping student engagement, and conversely, how does student engagement shape social interactions? (Ryu & Lombardi, 2015).

Hatano and colleagues emphasize that knowledge construction involves both social processes and substantial cognitive processes within an engaged individual mind (Inagaki et al., 1998). They advocate for a two-level analysis of students' activity where collective problem-solving and individual understanding are examined together. This approach highlights the importance of analyzing activities in the classroom also as a unit, to understand how students collaborate to reach a shared understanding. Simultaneously, we should observe individual students' changes, such as their awareness of the dissonance between their beliefs and the perspectives of others. This is because what is achieved collectively may not necessarily be shared at an individual level (Hatano, & Inagaki, 2013; Inagaki et al., 1998; Miyake, 1986). By analyzing constructive processes, meaning negotiation, types of arguments presented, and the depth of elaboration and perspective revision during these interactions, valuable insights can be gained regarding the mode and depth of students' engagement. In a similar vein, Ryu and Lombardi (2015) conceptualize engagement as "meaningful changes in participation" (p.71), i.e., as an interactive and evolving process involving both individual and collective dimensions situated within community as in a science classroom.

In examining learning, particularly in cases requiring conceptual changes, it's crucial to consider various domain-specific factors, as discussed earlier. These factors include children's prior knowledge, epistemic beliefs, and explanatory mechanisms they bring to discussions. Taking in mind the impact of such factors may furnish us with insights into the various forms of individual engagement that may arise within a same task and the personal and social experiences which may facilitate students' engagement. Additionally, it's essential to assess whether students can be persuaded during discussions, integrate new approaches, modify their initial ideas, and apply new concepts to solve new problems. The strength of prior knowledge as well as the student's commitment to it often play a significant, albeit indirect, role in influencing this process. This underscores the importance of taking into account multiple factors that impact the learning process and the reconstruction of knowledge, whether at the individual level or within the broader context. In this case, it is even more important to also capture and enhance productive classroom interactions conceptualizing engagement as situated within and embedded in these interactions. Indeed, observational protocols or discourse analyses have the potential to unveil how collective engagement contributes to individual learning. Furthermore, such methods can guide us in modifying the classroom settings to enhance their capacity to foster engagement (Pianta et al., 2012; Ryu & Lombardi, 2015).

Can educators enhance constructive and interactive mode of engagement in educational settings? The above discussion poses another challenge for researchers, emphasizing the role that educators play in designing tasks. Vosniadou and colleagues (2023) analyzed videotaped transcripts of lesson tasks using a coding scheme based on the ICAP (Interactive-Constructive-Active-Passive) model of cognitive engagement developed by Chi and her colleagues (Chi, 2009; Chi et al., 2018; Chi & Wylie, 2014). According to the ICAP model, other than differentiating between passive and active learning, there exist three distinct hierarchical modes -namely active, constructive, and interactive- linked to the concept of "active learning". These modes imply different underlying processes of knowledge change, and each one results in more effective learning than the previous one (Chi et al., 2018; Chi & Wylie, 2014). The findings revealed that most teachers tended to ignore the impact of their lessons on stimulating students' engagement. Furthermore, teachers designed only a few tasks aligned with the constructive or interactive modes of engagement, which foster deep conceptual understanding. Moreover, the results indicated that most of the whole-class discussions either failed to keep students engaged or engaged them only in an active mode. These discussions were not oriented towards generating constructive or interactive activity; for example prompting students to critically reflect on their learning, compare new concepts with their existing ones and other students' concepts, or transfer new knowledge to other domains. In such situations, educators offer reduced opportunities for interactions and engagement, possibly relying more heavily on passive modes of engagement (Vosniadou et al., 2023).

To enhance classroom interactions and student engagement, various professional programs for educators have been developed. For instance, the MyTeachingPartner (MTP) program employs a collaborative consultation process and web-based resources to deliver continuous, classroom-focused in-service training (Pianta et al., 2012). Another innovative curriculum resource is the Professional Student Program for Educational Resilience (PROSPER) designed to support educators in facilitating students' knowledge, momentary engagement and teachers' involvement with students (Torsney & Symonds, 2019). Chi (2021) argues that explicitly translating the ICAP theory as guidance for practicioners can empower them to enhance their lesson plans autonomously, applying the theoretical principles effectively (Chi, 2021; Stump et al., 2017). Consideration should be directed toward the significance of constructive and interactive task engagement in teacher education (Lawson et al., 2023). The question pertains to how we can enable educators to effectively transfer the knowledge aquired from education research into their teaching practices.

Conclusions

In the preceding sections, we discussed students' engagement during the complex, dynamic, underlying knowledge revision processes. Beyond more general factors, we argued that it is imperative to account for domain-specific factors in this process. In fact, these factors might play a different role in the context of conceptual change learning compared to traditional learning processes.

Believing in simple and certain knowledge imposes limitations on the potential of experiencing conceptual change and profound engagement. This belief encourages students to foreclose their thinking prematurely, preventing them from fully exploring alternative perspectives. Conversely, students who acknowledge that scientists (as well as students) construct knowledge are more inclined to undertake the cognitive effort required to facilitate change and constructively engage in the learning process (Hofer & Pintrich, 1997; Mason & Boscolo, 2004; Sinatra, 2005).

High prior knowledge can also function as an impediment to achieving conceptual change, especially when it conflicts with the established scientific explanations. Concurrently, in the relatively frequent situation, when the learners are unaware of this conflict, it is not evident that they will actively engage in constructive processes required for conceptual change learning. To illustrate, the robustness of pre-existing beliefs held by individuals with a strong interest in a particular topic could pose challenges to the process of knowledge revision (Dole & Sinatra, 1998; Murphy & Mason, 2006). A prerequisite, though, seems to be that students are also aware of the discrepancy between their prior knowledge and the scientific explanation, in order to engage in knowledge revision.

Prior knowledge appears to also influence the interpretation of the various cultural artifacts presented in the classroom. As previously mentioned, these artifacts do not convert information directly; instead, they undergo a constructive process where new information may undergo distortion to align with prior beliefs (Vosniadou et al., 2004; 2005).

Nonetheless, to attain a more nuanced comprehension of these domain-specific factors, it would be more advantageous to examine their combined patterns and their influence on engagement during the process of conceptual change rather than examining them in isolation (Cordova et al., 2014; Fredricks et al., 2004). In line with this argument, Fredricks et al. (2004) advocate for the adoption of pattern-centered analytic techniques in research, as opposed to variable-centered ones, as they could encompass a range of configurations of the different types of engagement.

What kind of learning environments do we need? What we require are learning environments and instructional methods that aspire to create motivated, intentional, proficient self-regulated learners who want to engage in meaningful, long-term learning (Sinatra & Pintrich, 2003; Vosniadou, 2003; Vosniadou et al., 2001).

In such a learning environment, the role of the instructor changes respectively. Educators must guide students in acquiring the skills of effective self-regulated learning, demonstrating and imparting various strategies for restructuring knowledge, such as analogies and model-based reasoning. Furthermore, educators should design meaningful learning activities to encourage metaconceptual awareness and epistemological sophistication. Importantly, these attempts cannot be achieved without substantial sociocultural support.

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ΒΙΒΛΙΟΓΡΑΦΙΚΗ ΑΝΑΣΚΟΠΗΣΗ | REVIEW PAPER

Επαναπροσδιορίζοντας την έννοια της εμπλοκής: Αξιοποιώντας τα δεδομένα από την έρευνα στην εννοιολογική αλλαγή

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ΛΕΞΕΙΣ-ΚΛΕΙΔΙΑ

Γνωστική εμπλοκή
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Προϋπάρχουσα γνώση
Επιστημικές Πεποιθήσεις
Πολιτισμικά τεχνουργήματα

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ΠΕΡΙΛΗΨΗ

Η τρέχουσα έρευνα στο πεδίο της γνωστικής αναπτυξιακής ψυχολογίας έχει αναδείξει μια πολυδιάστατη προσέγγιση για την έννοια της εμπλοκής, η οποία περιλαμβάνει τουλάχιστον τρεις βασικές συνιστώσες που εμφανίζονται ταυτόχρονα κατά τη μάθηση: μια συναισθηματική, μια συμπεριφορική και μια γνωστική. Ωστόσο, οι ερευνητές δεν συμφωνούν πάντα, τόσο για το τι περιλαμβάνουν οι συνιστώσες αυτές όσο και για τον τρόπο που αυτές αλληλεπιδρούν. Στην παρούσα εργασία, θα προσπαθήσουμε να συζητήσουμε αυτό το ζήτημα υπό το πρίσμα ενός συγκεκριμένου είδους μάθησης, της εννοιολογικής αλλαγής. Συγκεκριμένα, θα επιχειρήσουμε να εξηγήσουμε, με βάση ερευνητικά δεδομένα, πώς εσωτερικοί παράγοντες, όπως η προηγούμενη γνώση των μαθητών και οι επιστημικές πεποιθήσεις τους, μαζί με εξωτερικούς παράγοντες, όπως τα πολιτισμικά εργαλεία, μπορούν να επηρεάσουν τη «στιγμιακή» εμπλοκή των μαθητών, δηλαδή την εμπλοκή τους ανά μεμονωμένες στιγμές ενασχόλησής τους με επιστημονικές έννοιες, ειδικά σε περιπτώσεις που χρειάζεται να αναδιοργανώσουν τις αφελείς θεωρίες τους, προχωρώντας έτσι προς μια διαδικασία εννοιολογικής αλλαγής. Θα επικεντρωθούμε στο πώς αυτοί οι παράγοντες μπορούν να υποστηρίξουν την μάθηση, αλλά ταυτόχρονα μπορούν να αποτελέσουν και εμπόδιο στη στιγμιακή εμπλοκή στην τάξη στην περίπτωση της εννοιολογικής αλλαγής. Τέλος, θα συζητήσουμε πώς η κατανόηση της στιγμιακής εμπλοκής στο πλαίσιο της εννοιολογικής αλλαγής μπορεί να ενισχύσει την κατανόησή μας για το πώς να προσαρμόζουμε το ρυθμό ή την επιτυχία της εννοιολογικής αλλαγής, καθώς και το ποια είναι τα κατάλληλα εκπαιδευτικά περιβάλλοντα προκειμένου να επιτευχθεί η εννοιολογική αλλαγή.

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