

The Role of Metacognition in Abduction: A Goal Theoretical Perspective

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1. Introduction

Over the last few decades, calls have been increasing for education to foster active and critical thinking among students (Williams, Papierno, Makel, & Ceci, 2004). As a result, the role of abduction is becoming increasingly important in school instruction. Abduction is often described as a process of forming and evaluating explanatory or interpretative hypotheses based upon observations (Josephson & Josephson, 1994; Magnani, 2001). This is essential, both in science and in everyday life, in situations where individuals are compelled to give the best explanation in order to make good decisions and to behave wisely.

In school instruction, the implementation of abduction is most obviously called for when students engage in scientific inquiry, or in problem-solving activities (Lajoie, Lavigne, Guerrera, & Munsie, 2001). In such activities, students are asked to generate hypotheses to account for a set of data or phenomena. These activities are usually quite perplexing and call for a variety of cognitive skills (Kuhn, Black, Keselman, & Kaplan, 2000).

On the one hand, scientific inquiry entails effortful and persistent engagement on the part of students. On the other hand, however, there is a large literature concerning the difficulty of motivating students and maintaining their engagement, especially when the learning task is complex (Hidi & Harackiewicz, 2000). If students are not self-motivated and self-regulated when pursuing an inquiry learning task, hopes of promoting active and critical thinking will remain merely good intentions.

Metacognition, or the ability to think about thinking, has long been considered an essential component underlying the successful implementation of various cognitive processes (Bruer, 1993). Increased metacognitive awareness is not only considered a desirable outcome of inquiry learning (Karpov & Haywood, 1998), but also an important prerequisite for engaging students in inquiry. Although engaging in inquiry is both cognitive and motivational, the role of metacognition in relation to motivation has not received as much attention as its relation to cognition (Engeström, 1989).

In this paper, I propose to view metacognition as a mediator bridging the cognitive and motivational aspects of abduction in school inquiry tasks. First, I examine the cognitive and motivational aspects of abduction in science education in school. Second, I consider the contributions of metacognition to student engagement in abduction. In sum, I conclude that educational interventions that promote the development and implementation of metacognition will improve both the cognitive and motivational aspects of abduction in school.

2. The cognitive and motivational aspects of abduction in science education

2.1 *Abduction and the identification of abductive objects*

Abduction is defined as the “sequential comprehension and integration of data into a single situation model that represents the current best explanation of the data” (Johnson & Krems, 2001, p. 908). Three features of abduction portrayed in this definition are especially relevant here: situated, dynamic, and subjective, in addition to objective.

Abduction is situated because it is embedded in the individual’s interaction with the external world. For example, to initiate abductive processes, individuals must first perceive that an explanation is needed. Such a need arises from the individual’s interaction with the environment; therefore, an interpretation of the data precedes the abductive process. But interpretation alone does not determine when an explanation is demanded and what it needs to explain. That is, an initial interpretation of the data does not identify the object of the explanation, whereas an explanation is often triggered by an awareness of deficits or inconsistencies in one’s knowledge (Echevarria, 2003; Gendolla, 2001; Graesser & McMahan, 1993). In other words, identifying the abductive object entails comparing one’s existing beliefs and evidences revealed in the current situation, becoming aware of the incongruence between them, and discovering the anomalies.

Second, the dynamic of abduction lies in the fact that it is progressive; it continuously evolves as the evidence is obtained and processed incrementally. The outcome of each step in the abduction is the best explanation at that moment; this leads individuals to a further investigation of the problem and to the discovery of new evidence. Consequently, the abductive object is continuously evolving in this process. The advancement of abduction relies on the arrangement and implementation of a series of strategies used by individuals to reveal and handle new evidence. The available strategies, however, depend on individual competencies and available resources (e.g., instruments, references).

Third, there are subjective as well as objective criteria with regard to the *best* explanation. Constraints and affordances imposed by the task and its context constitute the objective criteria for the best explanation, whereas individuals’ appreciation of the current task and their competencies and motives for performing the task constitute the subjective criteria for the best explanation.

Because abduction is situated and constrained both by features of the individual and of the surrounding environment, the analysis of abductive processes should take both the individual and the particular context into account. Certain characteristics of school learning distinguish abduction in the classroom from abduction in other contexts, e.g. in laboratories of scientists. For example, what students are typically required to explain in school is determined by the curriculum. Although they can sometimes decide what particular aspect of the phenomena to explain, this is seldom the case. That is, the abductive objects are determined by the teacher through task descriptions or problem statements rather than through student self-reflection. Therefore, incongruence may exist not only between individual knowledge and current observations - which can trigger abduction - but also between the teacher’s hopes and the students’ task perceptions, which can hamper abduction.

In the above section, abduction is reconceptualized as a continuously evolving process of identifying problems (i.e., abductive objects) and resolving them. This process is situated in individuals' interaction with the external world and therefore has to be analyzed considering both the individual and the particular context. Before we proceed to the discussion of abduction in science education in school, the introduction of a goal as a construct related to both the individual and the task will be helpful, because such a construct incorporates both the cognitive and motivational aspects of a task.

2.2 Goals in abduction

Individuals usually have more than one goal when they undertake a certain task. These different goals are organized into a hierarchical and coherent goal structure. Different levels in this goal structure correspond to the activity structure (i.e. activity/motive, action/goal, and operation/condition) in Leontyev's (1979) thesis, where different hierarchies represent different levels of abstraction (Bracewell & Witte, 2003). The more concrete the goals, the closer they are associated with the means of attaining them, whereas the more abstract the goals, the closer they are related to individuals' sense of self. Moreover, different levels in the goal structure interact with each other.

Abduction is often motivated by the need to accommodate anomalous observations that reflect deficits in one's knowledge (Magnani, 2001). This is a goal that triggers the abductive process and is closely related to the action of carrying out abduction: It decides the abductive objects. Such an action goal is continuously evolving. As new information is incrementally obtained and processed, anomalies are constantly being redefined as a consequence of interactions between the phenomena - with its changing nature - and human cognition.

The action goal is also influenced by other levels in the goal structure. First, at a more abstract level of the goal structure, individuals also have purposes in carrying out abduction. Purpose refers to what one wants to accomplish by carrying out the abduction. The accomplishments of these purposes are realized through solving more concrete goals such as the resolution of anomalies. Abductive tasks may have different purposes including allowing further predictions or preventing undesirable events (Leake, 1995). The purpose of abduction affects the action goal. For example, in interpersonal situations in school learning, explanations are given in response to requests to solve puzzles. Thus, responding to a teacher's request constitutes the student's purpose in that situation. To accomplish this purpose, the student's immediate goal is to close the gap reflected in the teacher's request. In other words, the purpose of responding to the request determines the abductive object, which is the problematic aspect of a phenomenon to which the teacher calls attention.

Second, not only do purposes influence the goal of identifying the abductive object, but the condition under which an action is carried out also constrains and shapes the action goal. Such a condition affords opportunities for unfolding the action goal into concrete and realistic actions. The condition includes both the internal and external aspects of human cognition. Externally, the task environment determines the scope and extent to which one can access information (Goodwin, 1995; Hutchins & Klausen, 1996). This is especially the case when we are talking about scientific knowledge (Karpov & Haywood, 1998): The development of technology brings scientists into emerging territories of discovery and in part aids the advancement of

scientific knowledge. Internally, one's competency in respect of his/her knowledge of the subject matter and strategies also determines how far one can go with the investigation. In sum, having access to various scientific instruments and being equipped with a range of scientific knowledge and methods not easily available to others are important factors that distinguish scientists from non-scientists. They lead scientists to attend to phenomena of which non-scientists are not even aware (Williams, Papierno, Makel, & Ceci, 2004).

Besides being hierarchical, goal structures are also multi-faceted. An individual can be committed to different goals at the same time, either actively or passively. For example, students may enter into abductive tasks with different purposes; e.g., demonstrating their ability, pleasing the teacher, or merely finishing the assignment. These different purposes may be held separately or in different combinations. Different goals may come into conflict and lower the individual's commitment to any one of them.

The goal structure is not only a characteristic of the individual, but also of the task, which is defined as "the goal given under certain conditions" (Leontyev, 1979, p. 63). The task goal can be decided both intrinsically and extrinsically. Intrinsically, the task goal may emerge with the goal of problem-solving; extrinsically, the task goal may be assigned by a person other than the problem-solver. Consequently, the goal structure of the task and of the individual may not coincide. This point is especially important in school, where most learning tasks are assigned by the teacher. The incongruence may occur at different levels in the goal structure. Such inconsistencies contribute both to the complexity and to the source of the dynamic of inquiry learning.

In sum, the construction of the goal is very important in triggering and promoting engagement in abduction. But at the same time, the presence of different goals may bring about goal conflict hindering engagement.

2.3 Abduction in science education

2.3.1 The cognitive aspect: Potential difficulties in deciding action goals

In cognitive psychological terms, many of the abductive tasks performed in school fall into the category of ill-structured problems, as compared with well-structured problems (Bruer, 1993). Recall that *problem* is a special construct in cognitive psychology. A problem comprises an initial state, a goal state, and operators. The problem-solver is hypothesized to construct a problem representation, which is also called a *problem space*. This includes a set of possible paths that connects the initial state and goal state through the arrangement of different operators. Ill-structured problems are those that do not have ready and clearly defined initial representation in terms of initial state, goal state, and possible solution paths. Identifying the abductive object involves constructing both the initial state and goal state, i.e. deciding what the problem is and the state after resolving it. The construction of the initial state and the construction of the goal state are interdependent. On the one hand, once the observation has been interpreted and the initial state set, the goal state is also determined. On the other hand, because the problem of ill-structure is equivocal and uncertain, it is difficult to interpret the phenomena and construct the initial state. One's purpose will constrain the goal state, which in turn helps to form the initial state.

A correct appreciation of the action goal of abduction entails a correct representation of the problem space. Consequently, the difficulties pertaining to the construction of the problem space in the inquiry task bring about the potential difficulties in deciding the action goals of abduction. In inquiry learning, students are presented with phenomena and are asked to explain them. Such a situation is quite opaque to the students because: (a) they need to identify and determine the problematic aspect in the phenomena upon which their explanation will focus; and (b) the cause of the problem is not presented and has to be inferred. Inquiry learning demands analytical thinking skills such as the ability to evaluate the data and the ability to distinguish between appearance and reality. Not all students can handle these processes without difficulty. In contrast, students have been documented to display various kinds of fallacious reasoning that has led them to misunderstand the task and represent the problem incorrectly (Zeidler, 1997), i.e. students may misrepresent the abductive object, which consequently leads to the misconstruction of the action goal.

Moreover, the process of abduction requires reconstruction of the problem space with the accumulation of new evidences. This process relies on the student's competencies in obtaining and processing new information, for which various cognitive strategies are required. In addition, students must also have the necessary skills for dealing with certain experimental instruments.

2.3.2 The motivational aspect: Various motives of students and their impacts on engagement

Besides embracing the learning goal assigned by the teacher, students may have varieties of motives at the time of undertaking the task. Not all of those motives are productive - some of them may even be in conflict with the teacher's purpose in having students fulfill the task. The conflicts between goals may lower student commitment to the learning goal, resulting in student disengagement from the task.

First, students are likely to have a self-serving motivation (Klaczynski, 1997) when carrying out abduction. When the outcome of the desirable abduction results in a conclusion that contradicts a strongly held belief or personal theory, students appear to have various negative responses such as discrediting the evidence and hesitating to accept the abductive conclusion (Chinn & Brewer, 1993).

In addition, because many of the tasks involving abduction are perplexing and demand a great deal of effort, students may not necessarily consider the task attractive and worth devoting their energies to. Consequently, students may develop various reactions that indicate their lack of cognitive engagement with the task. First, because many of the inquiry tasks take the form of working in a group, a student may sit back and allow his/her classmate(s) to complete the task. Second, a student may *passively* accept the task and follow what the teacher or other more competent peers say. Students, especially in higher grades, may possibly consider the inquiry task a trick played by the teacher and may have developed methods to cope with this. For example, students may merely parrot the recently taught theories and the recently assigned readings in the hope of stumbling on a *correct* answer, since the content of the inquiry task typically corresponds to the class syllabus. Such a parroting strategy is not desirable because it does not always reflect a genuine understanding of the course material and prevents students from developing critical thinking habits. Moreover,

although students passively accept the scientific principles or theories as assertions of absolute truths, without carefully and critically considering this information, students are unable to apply it in flexible and practical ways. However, although undesirable, this parroting strategy can be transformed and may lead to genuine learning. This topic will be considered later in this paper.

3. Metacognition, abduction, and science education

3.1 Metacognition: From cognition to motivation

Traditionally, metacognition is defined as cognition about cognition. It refers to one's knowing concerning both cognitive processes and products (Flavell, 1976). Accordingly, Deana Kuhn (1999a, 1999b, 2000) proposes two types of metacognition: metacognitive knowing, and metastrategic knowing. This distinction corresponds to the widely used dichotomy in cognitive psychology between declarative knowledge and procedural knowledge. That is, metacognitive knowing knows *that*, whereas metastrategic knowing knows *how*.

Besides the process vs. product dichotomy, the objects of metacognition as a form of meta-knowing are further expanded in recent study. First, rather than defining metacognition as cognition concerning one's own cognition, Kuhn (1999a) suggests that metacognition can be both personal and impersonal. Personal knowing is knowledge about one's own knowing and impersonal knowing is knowledge about others' knowing.

Second, metacognitive knowing could be further distinguished according to whether its object were specific and situational, or general and more abstract (Kuhn, 1999a, 1999b, 2000). Specific and situational metacognitive knowing deals with one's awareness pertaining to a specific piece of knowledge. That is, what do I know about this topic and what is the source of this knowledge? The general and more abstract metacognition refers to one's epistemological understanding, which deals with one's general understanding of knowledge and knowing. That is, how does anyone know and what does one know about one's own knowing?

Finally, from a cultural-historical perspective, Engeström (1989) calls for attention to be paid to both the contextualized and motivational aspects of metacognition:

a truly high level of metacognitive awareness in learning requires (a) conscious analysis and mastery of not just discrete learning situations but of the continuous activity context in which the situations are embedded (whether they be situated within school-going, work, science, art, or some other activity), (b) not just balancing the components of the learning situation but 'seeing through' the inherent contradictoriness of the learning task, i.e. their double nature as unities of exchange value and use value. (p. 130)

3.2. Metacognition and abduction in science education

As discussed above, abduction in the school context is associated with various goals, and goal conflicts may occur, hindering student engagement both cognitively and motivationally.

With respect to the cognitive aspect, goal conflicts result in the incorrect construction of abductive goals; this includes both the failure to represent the initial problem space correctly and the failure to obtain and process new information appropriately. Both failures draw students away from engaging in abduction that leads them to the best explanation.

But these failures also indicate opportunities with which instruction can interfere because they point out where the students' knowledge structure and/or problem-solving skills fall short. The key to successful instruction, I would claim, rests upon interventions that improve student metacognition. The importance of metacognition in problem representation and evidence evaluation has been discussed extensively elsewhere (e.g., Bruer, 1993). In relation to abduction, I would like to reaffirm that metacognition aids the correct appreciation of abductive goals and therefore helps to trigger and promote the abductive process.

In regard to the motivational aspect, goal conflicts result in various passive and negative coping strategies in students. Cognitive demands imposed by the abductive task require the efforts of students, whose goal may be to conserve their own cognitive resources. Alternatively, they may simply consider the task uninteresting or not worthwhile completing. Some examples are given below of the coping strategies of students who are disengaged from school learning tasks, highlighting the role of metacognition.

First, students may rely on simple heuristics to solve problems. With increasing metacognitive awareness, students may come to realize that some of their heuristics are unfounded, unproductive or even fallacious. Such awareness, in turn, will direct students towards more desirable, though possibly more demanding, abductive reasoning processes.

Second, students may passively parrot what others (e.g., teacher, more competent peer, or textbook instruction) tell them to be the case. This may not necessarily reflect their unwillingness to commit themselves, but rather their hesitation to voice their own thinking in front of authorities. Because there is only one "officially" correct answer, repeating what is taught is generally safer, even though what they are actually thinking may be quite different. Gradually, students become disengaged from the abductive process in inquiry learning because they have formed an impression that inquiry learning is just one of the many tricks played by the teacher and the teacher only wants the final correct answer. Two reasons related to metacognition might lead to such an impression:

1. It reflects a biased epistemological understanding of the student: Scientific knowledge is about facts derived from reality and is irrefutable; if I think differently then I am wrong and incompetent.
2. It shows that students focus too narrowly on the exchange value of knowledge rather than becoming aware of the contradiction associated with the learning task (Engeström, 1989). That is, students do not realize that although the passive learning strategy may bring them good grades, it deprives them of opportunities to expand the use value of knowledge.

However, with proper instruction, a passive strategy such as parroting can be transformed into more genuine learning. When students are *articulating* (Kuhn & Lao, 1998) the scientific theory or principle - even though they are doing so passively - they

are making the first step toward engagement: they are taking a position. Without such an articulation, students may not even bother to think about those theories or principles. The question left for instruction would then become how to structure the learning context in a way that aids students in defending and justifying their positions. The solution to such a problem, in turn, relies on interventions that facilitate students' metacognition of the cognitive aspect of abduction.

4. Conclusion

This article begins with an examination of both the cognitive and motivational aspects of abduction and highlights the role of goal. Goal is organized in a hierarchical and coherent structure. It is very important in triggering and promoting student engagement in abduction. Commitment to several goals at the same time may bring about goal conflicts, which may hinder student engagement in abductive activity; but they also provide opportunities in which interventions can interfere. Metacognition, as the awareness of both cognitive and motivational states, is proposed to attenuate the negative effects of goal conflicts and lead to genuine learning. Therefore, success in fostering active and critical thinking through inquiry learning rests on interventions that facilitate metacognition. An increase in metacognitive competency is not only a desirable consequence of inquiry learning, but metacognition is also an essential component that safeguards student engagement in inquiry.

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