VIENNOT L. & DÉCAMP N. 2018. Concept and critique: Two intertwined routes for intellectual development in science. In *Complementary and Converging Perspectives on Conceptual Change*, T. Amin and O. Levrini, New York: Routledge, 190-197

Concept and critique: Two intertwined routes for intellectual development in science

Laurence Viennot and Nicolas Décamp

Introduction

The point of departure for the views presented here is an epistemological position: that physics is a science that aims at a coherent and parsimonious description of the world, in which a limited number laws account for a large set of phenomena within a specified range of validity. Within this framework, coherence should be a pillar of physics education. Coherence can be defined (in a compelling if somewhat negative way) as *not claiming both a thing and its contrary*. In particular, this means not claiming something contrary to any laws of a physical theory that would at the same time be admitted as valid (such as Newton's laws, or any personal 'theory') for the model adopted. Here, the word 'model' refers to a reductive description of the situation at hand, in which some features are chosen *a priori* as relevant. In particular, it would be incoherent to continue to adhere to the same model and theory where a prediction does not conform to an experimental fact. In such cases, either the model or the theory must be changed.

On this definition, coherence can be seen as a criterion for assessing the accuracy of a learner's view or line of reasoning. In more positive terms, coherence can be understood as a kind of compass that orients a student's scientific formation; this is to characterise intellectual development in science as a pathway that leads learners to more coherent analysis of the material world. A major question then arising is how to document learners' intellectual development and the conditions most likely to favour it. In the first place, this requires more precise analysis of what constitutes intellectual development—a need reinforced by recent developments in science education.

In recent years, science teaching objectives for secondary education have placed more emphasis on skills than on concepts. In some cases (EC 2015), the development of critical faculties has become a key objective, risking a relative disregard of conceptual structuring. Indeed, there is already alarming evidence to this effect, as for instance in Norway and Sweden (Lie *et al.* 2012). In this context, it seems important to explore the interplay between the development of conceptual understanding and critical attitude, and to ask whether students can really develop either without the other (Henderson 2015). This constitutes the main research question for the series of investigations outlined below. By way of grounding, the components of intellectual development will first be discussed.

Standpoints on intellectual development

To begin, we would like to take a step back from the idea of intellectual development as a succession of conceptual changes. As is well documented, how people reason in science—students, teachers, authors, lay people—is sensitive to the particular context, physical situation and language in which a question is posed. Such reasoning has therefore been characterised as the emergence of 'knowledge in pieces' (diSessa 1993). But because such occurrences are transversal, extending to other domains (e.g. linear causal reasoning, Viennot 2001), they may be seen as theory-like (Vosniadou 2002). More importantly, and perhaps because of their transversal character, such lines of reasoning survive local changes in a person's views. This is why, we prefer to speak of conceptual *development* rather than conceptual *change*.

That said, intellectual development is not reducible to conceptual development; clearly, the development of a critical attitude is also an essential component of intellectual development. For present purposes, then, the key question is whether students can develop a critical attitude independent of conceptual understanding. To address this question, we focus on the issue of coherence as defined above. We also investigate to which extent students detect incomplete explanations. In so restricting our investigation, we exclude much of what is characterised as critical thinking by cognitive scientists, whose definitions are much wider. For instance, we do not consider here students' ability to criticize public accounts of science with respect to possible asymmetric relationships of power, nor do we consider other abilities such as those listed by Jiménez-Aleixandre and Puig (2012).

It is worth noting that adopting a critical stance to any explanation requires awareness of one's own state of comprehension—a metacognitive dimension that indicates something of what it is to learn science. Although the connection between critical thinking and metacognition is not always acknowledged (e. g. Zohar & Barzilai, 2013), some authors (e.g. Vermunt 1996) explicitly link the two. We share this view of critical stance as a component of metacognition—that is, as an essential condition for active self-regulation of one's own learning processes. Enacting a critical attitude is also a means of expressing dissatisfaction; in this light, such a stance can also be viewed as a search for intellectual satisfaction [Viennot 2006, 2014; Feller *et al.* 2009; Mathé and Viennot 2009]. Consequently, the inquiries reported below deploy some markers of intellectual satisfaction. We further consider that posing questions that directly challenge an explanation indicates an active search for meaning beyond an attitude of mere doubt, perhaps relating to psychological factors such as self-esteem or self-efficacy (Bandura 2001). As these metacognitive and affective components of critical attitude seem *a priori* difficult to unravel, they are designated here as 'metacognitive-critical-affective' (MCA).

Studies of the co-development of conceptual understanding and critical attitude in advanced physics students

Main features

To document possible links between conceptual understanding and critical attitude, taking account of MCA factors, we chose to conduct in-depth case study investigations based on extended individual interviews. For each study, we designed conditions for a 'concept-driven-interactive pathway' (CDIP, seeViennot & de Hosson 2015). This takes the form of a series of events—inputs from the interviewer and responses from the student, possibly involving experiments, questions or requests and discussion—oriented towards concept acquisition. As in the teaching experiment method (Komorek & Duit, 2004), the interaction is structured and guided to allow students to express their initial thoughts and reactions to various events. A CDIP is also progressive, in that what is understood at a given step may serve to construct the next stage of knowledge, and it offers students opportunities to critique presented textual or iconic explanations.

Within this framework, knowledge that is 'already there' may be reorganized and extended during the interview. Although resembling a teaching-learning format, this interaction is used as a research tool— not to evaluate a learning sequence but to address specific research questions. We examined how MCA factors might evolve in conjunction with conceptual comprehension by capturing students' *intellectual dynamics* during their interaction with the interviewer—that is, the interplay between conceptual and MCA factors. In each case, the sample comprised between 7 and 14 third- or fourth-year university students. Each study is centered on a different physics topic, such as hot air or helium balloons, radiocarbon dating or survival blankets. In assessing critical development, we explored interviewees' capacity to detect and analyse incoherent or incomplete explanations.

First example: radiocarbon dating

The topic of radiocarbon dating is well suited to our purposes, in that it seems well known, but its detail is far from obvious, and many incomplete explanations can be found in popular accounts. In fact, beyond the exponential decay of radiocarbon in dead organisms and the role of ^{14}C half-life (5730 years), a *relatively* complete and coherent explanation of this process should at least include the following conceptual nodes:

1 the need to know the initial proportion of radiocarbon to ordinary carbon in an organism at the time of its death;
2 the uniformity of this quantity in the atmosphere and living beings;
3 the constancy in time of this quantity;
4 the process of formation of radiocarbon;
5 the process of radioactive decay of radiocarbon;
6 how the balance between the corresponding numbers per second of radiocarbon atoms involved in these two processes results in a steady value of [$^{14}C/^{12}C$] in the atmosphere;
7 the constancy of the total number of nuclei (radio carbon + nitrogen);
8 the multiplicative effect of the existing numbers of radiocarbon and nitrogen nuclei in the destruction and creation of ^{14}C nuclei, respectively;
9 how this multiplicative structure explains the stable proportion of radiocarbon to ordinary carbon in the atmosphere.

For this investigation (Décamp & Viennot 2015), we selected five documents from the Internet that provided incomplete explanations as compared to the above list. Using conceptual nodes 7, 8 and 9, we also designed a sixth document to explain how a steady state ^{14}C population can be reached and maintained from an unbalanced initial situation. Ten prospective teachers were then presented with these documents in order of increasing completeness. For each document, the interviewee was invited to state to what extent they were satisfied, or whether they would need further information. An example of a response considered to exhibit a critical attitude would be "How is it that there is a constant proportion of radiocarbon in the atmosphere? There is no radiocarbon decay in the atmosphere?" It is important to note that posing such a question does not, in principle, require much knowledge of physics.

Transcripts were processed at two levels of analysis: a conceptual level (which is not commented on here) and MCA aspects. Our MCA indicators included levels of agreement, types of questions posed (i.e. anecdotal or 'crucial', as above) and levels of intellectual satisfaction or frustration. The findings indicated that most students need to reach a threshold of comprehension *beyond mere logical necessity* before activating their critical potential. Once this (student-dependent) threshold is reached, agreement, moderate satisfaction and anecdotal questions disappear, being replaced by frustration, crucial questions, critiques (including self-critiques) and an active search for comprehension until the student is finally satisfied with the last explanation. We describe this dynamics of co-development as 'delayed critique'.

For a minority of participants (2/10), we also observed a persistent absence of critique, regardless of the incompleteness of the explanation at hand. These students already knew the topic very well. They were happy with their own responses and (therefore?) neglected to consider the texts for what they were—that is, deeply incomplete. It may be that they unconsciously completed what they were reading; we describe this syndrome as ‘expert anesthesia of judgment’.

Previous and subsequent studies: converging results

The findings of this investigation align with previous results and are built on in subsequent investigations. Specifically, ‘expert anesthesia of judgment’ had already been observed and analyzed in physics teachers. For instance, a hot air balloon is nearly always presented as isobaric (see for instance Giancoli, 2005) when calculating the internal temperature needed for take-off. If teachers see no objection to this hypothesis (N = 129/130, Viennot 2011), it is not because the textbook writers or teachers have ignored the law of fluid statics. Their knowledge in this domain should suffice to indicate that an isobaric situation inevitably results in a crash, given that all kinds of flotation link to a gradient of pressure, or that the same pressure on both sides of an envelope cannot result in a force exerted on this envelope. In this case, the observed critical passivity may reflect the fact that this inconsistent hypothesis leads to a correct solution via calculation of Archimedes’ upthrust, which falls within teachers’ expertise.

Another experiment looked at a popular commentary on the world freefall record. It was said that the hero ascended to an altitude of 40,000 meters in an helium balloon before jumping out, and was then in freefall, given ‘the absence of an atmosphere’. Twenty-three PhD students and six in-service teachers were asked individually whether they would pose any questions to grade 10 students to help them comprehend this text (Viennot 2013). Despite their sufficient expertise, none of the participants mentioned that a helium balloon cannot reach a place where there is no air.

With regard to ‘delayed critique’, some instances were also observed in an investigation involving 14 third-year university students of scientific mediation (Mathé and Viennot 2009). These prospective journalists were asked for their opinions about an article explaining how a hot air balloon works. This paper mentioned the usual inconsistent hypothesis, and while interviewees did criticize the paper after realizing that the hypothesis was absurd, there was in most cases a notable delay in so doing.

In one subsequent investigation, a small group (N = 7) of prospective teachers in fourth year at university were interviewed about phenomena related to a survival blanket (Viennot and Décamp 2016). Again, we observed a dynamics of ‘delayed critique’ (6/7). In this case, unlike the previous studies, a preconception strongly influenced students’ judgments—that the best possible way to protect against cold with a survival blanket was to ensure the maximum reflection of ‘heat’ towards the body. Not surprisingly, then, participants were found to have difficulty in critiquing texts presenting the same view. In one case, however, an element of information available from the start (that the gold side is more emissive and less reflective than the silver side) was used to trigger an ‘early critique’, confirming that this dynamics was logically possible. In contrast, none of the students were subject to ‘expert anesthesia of judgment’, given that none were experts on this topic.

Concluding remarks

The present paper synthesizes a series of investigations based on in-depth interviews about several physical situations, bearing on what appears to be the *co-development* of conceptual comprehension and critical attitude. These studies highlight the metacognitive, critical and affective aspects of interviewees' comments, and several dynamics of co-development are characterized. 'Delayed critique' is perhaps the most frequent dynamic in the case of non-obvious topics, where a threshold of comprehension has to be reached, beyond mere logical necessity, before a student activates their critical potential. The case of 'early critique', probably infrequent for non-obvious topics, arises where a student makes use of what they already know to pose relevant questions without inhibition, despite their incomplete comprehension of the topic. In contrast, 'expert anesthesia' of judgment designates a lack of activation of the critical attitude, despite a high level of conceptual structuring. On this (still exploratory) basis, we suggest that further research should continue to explore the entangled processes of conceptual and critical development in students and teachers. In particular, it seems relevant to investigate how students can be helped to use what they already know—a kind of 'conceptual parsimony'—to activate their critical potential. To this end, we suggest that correlation-based studies will probably not suffice. Instead, our findings support the need for in-depth analyses of students' *intellectual dynamics*—that is, of intervening *processes* during interaction with a teacher or with other students in constructing critical judgments of the coherence and completeness of scientific explanations.

Bandura, A. (2001). Social cognitive theory: an agentic perspective, *Annual Review of Psychology* 52, 1–26.

Décamp, N. & Viennot, N. (2015). Co-development of conceptual understanding and critical attitude: analysing texts on radiocarbon dating, *International Journal of Science Education*, 37, 2038-2063 http://dx.doi.org/10.1080/09500693.2015.1061720.

European Commission (2015). *Science Education for Responsible Citizenship* Report EUR 26893 EN chair Hellen Hazelkorn Brussels

Feller, I., Colin, P., & Viennot, L. (2009). Critical analysis of popularization documents in the physics classroom. An action-research in grade 10. Problems of Education in the 21stCentury, 17, 72-96

Giancoli, D.C. (2005). Physics (6th ed): Instructor Resource Center CD-ROM, *Prentice Hall.*

Henderson J.B., MacPherson A., Osborne J. & Wild A.(2015). Beyond Construction: Five arguments for the role and value of critique in learning science, *International Journal of Science Education*, 37:10, 1668-1697, DOI:10.1080/09500693.2015.1043598

Jimenez- Aleixandre, M. P., & Puig, B. (2012). Argumentation, evidence evaluation and critical thinking. In B.J. Fraser, K. Tobin, & C. McRobbie (Eds.), Second international handbook of science education (pp. 1001–1015). Dordrecht: Springer. doi:10.1007/978-1-4020-9041-7

Komorek, M. & Duit, R. (2004) The teaching experiment as a powerful method to develop and evaluate teaching and learning sequences in the domain of non-linear systems, *International Journal of Science Education* **26**(5), 619-633.

Lie, S., Angell, C. & Rohatgi, A. (2012). Interpreting the Norwegian and Swedish trend data for physics n the TIMSS Advanced Study , Nordic Studies in Education, Vol. 32, pp. 177–195 Oslo

Mathé, S. & Viennot, L. (2009). Stressing the coherence of physics: Students journalists' and science mediators' reactions *Problems of education in the 21st century* **11**(11) 104-128

DiSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and instruction*, *10*(2-3), 105-225.

Vermunt, J. D. (1996) Metacognitive, cognitive and affective aspects of learning styles and strategies: A phenomenographic analysis. *Higher Education* **31** 25–50. doi:10.1007/BF00129106

Viennot, L. (2001) Reasoning in physics (chap. 5) Dordrecht: Kluwer

Viennot, L. (2006) Teaching rituals and students' intellectual satisfaction, *Physics Education*, 41, 400-408.

Viennot, L. (2013) Les promesses de l'Enseignement Intégré de Science et Technologie (EIST): de la fausse monnaie? *Spirale* n° 52, 51-68.

Viennot, L. (2014) *Thinking in Physics The Pleasure of Reasoning and Understanding*, Dordrecht : Springer

Viennot, L. & de Hosson, C. (2015) From a Subtractive to Multiplicative Approach, A Concept-driven Interactive Pathway on the Selective Absorption of Light, *International Journal of Science Education*, 37:1, 1-30. DOI: 10.1080/09500693.2014.950186

Viennot, L. & Décamp, N. (2016). Co-development of conceptual understanding and critical attitude: toward a systemic analysis of the survival blanket, *European Journal of Physics*, 37 (2016) doi:10.1088/0143-0807/37/1/015702

Vosniadou S. (2002). On the nature of naive physics. In M. Limon & L. Mason (Eds.), *Reconsidering conceptual change: Issues in theory and practice* (pp. 61-76). Dordrecht: Kluwer.

Zohar, A., & Barzilai, S. (2013). A review of research on metacognition in science education: Current and future directions *Studies in Science Education*, **49**(2), 121–169. doi:10.1080/03057267.2013.847261