Learning in the laboratory: an interactional, factual and conceptual experience.

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LEARNING IN THE LABORATORY: AN INTERACTIONAL, FACTUAL AND CONCEPTUAL EXPERIENCE

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Abstract

When the teacher acts in a particular way, how does the student probably experience his act? What is the nature of these experiences and how teachers may influence them? Our starting point was a three-dimensional model (subject, object, project) defining three domains of experience: the interactional, perceptual domain, the conceptual, mental domain and the factual, concrete domain. We adapted this theoretical framework to the context of learning in the laboratory. It is assumed that all three domains are present in any learning experience but that some laboratory sessions may be dominated by one or the other domain. We present the consequences of this model for the design of laboratory sessions. Three types of laboratory situations are presented that lead to different natures of student experience and that are possibly connected to different learning outcomes. Using the framework, we derive the problems involved in using only one type of laboratory. Finally, we argue that if several types of laboratory calling on different domains of human experience are proposed, laboratory work becomes a privileged activity in which these domains can be used for learning purposes.

Background and questions

Hofstein and Luneta (2003) define science laboratory activities as "learning experiences in which students interact with materials and/or with models to observe and understand the natural world". Students learn by performing concrete activities, by comparing experimental data to a model, and/or by designing an investigation. The second generation of cognitive science (Klein, 2006; Prain & Tytler, 2007) now associates conceptual knowledge for learners with more sensitive, perceptual and concrete experiences. The questions raised are thus the ways in which perceptual and concrete approaches can be used in the design of laboratory work, and the reasons for which it is important that they be taken into account. We propose a model for the analysis and design of laboratory work that focuses on the nature of student experiences induced by the teacher. We will hereafter use the term 'labwork' to refer to laboratory work (Tiberghien et al., 2001).

Many authors insist upon the uniqueness of the learning experience in the laboratory. White (1996) claims that it is the quality of the experiences that students have there that is critical. What is unique to labwork? In some situations, labwork is the only means (or at least a privileged means) by which to teach manual dexterity - including fine movements, precision and care - and the acquisition of specific techniques. The lab is also a place where students can be taught how to design and conduct an investigation in order to solve a scientific problem (Hofstein & Lunetta, 2003; White, 1996). For some researchers and teachers, the added value of labwork is that it enhances motivation, and stimulates excitement by providing unusual objects and events - a contrast with the usual learning experience of sitting still and listening or doing exercises. Moreover, the laboratory is said (Hofstein & Lunetta, 2003; White, 1996) to be a place where personal experience can be linked to a scientific way of reflecting on that experience (using scientific representations of the world such as models). The students' personal experiences are either their direct observations of a phenomenon through hands-on manipulation or their recollection of past experiences (e.g. in a Mechanics course a teacher could ask students: "What did you feel when the elevator started or stopped?"). Understanding student's personal experience more effectively is essential in order to create a learning situation that encourages and challenges students to develop experimentally-based inquiry skills. Laboratory work involves thinking, feeling and doing, and the lab is a hub of interactions between these three aspects. To elaborate on this, we will first review the literature on discussions and evidence as to how feeling and doing provoke learning in the laboratory.

This paper addresses the following questions: What is the nature (the different domains) of students' experience during a laboratory session? What are the teachers' acts that lead to different natures of student experience? In the following parts of this paper, we will firstly propose a framework derived from a theory (with a brief introduction to that theory), which suggests an answer to our first question. We will then present empirical studies to answer to our second question. These studies have enabled us to build tools from the proposed framework and to illustrate the concepts introduced by means of concrete examples. Finally, the discussion raises the consequences for the design of labwork.

Literature review

A range of different tools and frameworks have been proposed to categorize and study different learning domains, and the goal here is merely to provide a rapid overview. One of the earliest and most widely used systems is the Bloom taxonomy, with its three learning domains: the cognitive, the affective and the psychomotor. Bloom worked on the cognitive domain (1956), while the affective domain was later developed by Krathworhl et al. (1964). Simpson and Harrow ultimately provided a classification of the third domain, the psychomotor domain: see e.g. Bergendahl (2004), or Forehand (2005) for a historical review.

There are a number of definitions concerning the affective domain, which accordingly comprises several sets of variables, see e.g. Gungor et al. (2007). A wide range of affective factors have been studied, including interest, motivations, feelings, emotions, values, or attitude toward science. In a review on learning and teaching in the affective domain, Miller (2005) adopts the view that this domain covers attitudes, motivations and values. She argues that there is a need for theory, and proposes several frameworks from psychology to educational sciences. Nieswandt (2007) considers interest, self-concept (perceptions and belief about oneself based on past experiences) and attitudes as the main affect components, in a study of the relationship between affective and cognitive variables in high school students taking chemistry for the first time. Several authors in the literature of science education acknowledge the fact that learning is influenced by affective factors (see e.g. the special issue of the Journal of introduced by Alsop and Watts 2003). However, there are few empirical studies on how it may do so in this field (Hofstein & Lunetta, 2003), although many authors stress that the laboratory provides a complex perceptual experience (e.g. Gooding, 1992). Alsop and Watts (2000) explore the issue of students' feelings about a topic (in this case, radioactivity, which aroused mostly negative feelings) to determine whether or not these feelings influenced their approach to learning. In their view, the aim underlying the introduction of non-purely cognitive learning is to depart from impersonal and "antiseptic" science (Alsop & Watts, 2000). In a study of relationships between achievement and affective characteristics in physics freshmen, Gungor et al (2007) put forward two arguments for the importance of affective factors for learning. The first of these is the impact of affective factors on achievement, and the second is the fact that affective factors are more important for life in society than cognitive factors and should be given priority. The latter is related to the loss of interest in science: "students think that science is not related to them" (Gungor et al., 2007).

Prain (2007) shows that when a perceptual approach is used when learning science, students make sense of phenomena by drawing on perceptual links. He considers that a perceptual approach increases the construction of the individual path to meaning. For Coquidé (2000) the connection with reality has at least two effects. Firstly, effective and authentic practices allow the discovery of techniques and of their constraints, and contribute to a choice of positive vocational guidance. Secondly, they lead the learners to be aware of the need to manage the materiality of sciences, an essential element of any scientific or technical culture. As stated by Gooding (1992), the dominance of head over hand leads to an intellectual view of science, and the way in which kinesthetic activities provoke learning in the laboratory is therefore still unclear, and challenged. Several authors discuss the relationship between doing and learning in the laboratory, for instance between practical actions and reflection on scientific theories behind these actions. This relationship can make things more concrete by illustrating abstract phenomena and concepts and by making the facts visible. Millar (2004) defines practical work as: any teaching and learning activity which involves at some point the students in observing or manipulating real objects and materials. Millar (2004) wants to promote "knowledge in action", and a more explicit, reflexive and declarative knowledge. He claims (Millar, 2004 p.2) that "as Piaget argued, it is by acting on the world that our ideas about it are formed and develop. Students need to have experiences of acting on the world, in the light of a theory or model, and seeing the outcomes".

It is not easy to separate thinking from doing or feeling and study their impact on learning. Because these three domains are always present in any learning experience and particularly important in those that take place in the laboratory, there is a need to define them in a single framework. However, few authors have worked towards establishing consistency between these three domains, particularly in research in science teaching.

Proposed theoretical framework

We would first like to state explicitly our position on both learning and knowledge. Our position on learning comes from Dewey (1938/1968), who considers that research on learning needs a theory of experience. Furthermore, our position on knowledge of the natural world is summarized by Bachelard (1934/1985, p. 15), who expresses the notion of a three-dimensional reality as follows: the subject cannot reflect on the object without considering the project. Let us take an example to illustrate the notion of a project: I (subject) use a pen (object) to write here and now (project), but I can have many other projects for this pen, for instance using it later to dial a number on a phone. This experience of interaction with an object, the pen, is fully described only through the project. From Bachelard's point of view, reality is not reduced to an interaction between subject (a scientist or a community) and object (devices, materials and phenomena of science). There is a third dimension, which is the project that allows considering the spatial and temporal deployment of the reality under consideration.

The aim of our second research question was to understand the student's experiences as organized by a teacher in the laboratory, that is, to infer the students' learning experiences from what the teacher does and asks them to do. To analyze teachers' discourse and writings, we used a framework that is coherent with the two positions mentioned above. We found a way to elaborate on Bachelard's view of reality by using the Theory of Sense and Human Coherences (Nifle, 1986). This theory is presented in a French philosophical essay, Nifle (1986), and used mostly in non academic situations (but see a recent study on teaching modeling, Ney, 2006). Sense is a specific view of the world, a specific logic, held by an individual, a community or an institution, according to this theory. This view reveals itself in attitudes, behaviors and representation, giving an orientation and a coherence between thought and action. The theory is based on three assumptions: (1) reality (what one can consider, apprehend) is always a life experience (2) reality is an instance, a product, of a shared Sense, and (3) reality is described by three variables or dimensions, subject–object–project (figure 1).

Figure 1. Coherentiel.

From these assumptions, Nifle (1986), and see also (Ney, 2006), introduces a three-dimensional structure called a coherenciel and formed by
- the subject dimension (pointing upwards in figure 1) is the expression of an intention, the desire to consider an object or a phenomenon. This intention can have many forms: desire, motivation, tendency, aspiration. Indeed, any reality is that of a particular person (or community or institution)
- the object dimension (pointing downwards, left) is what can be distinguished from its context and also from ourselves by the attention that we pay to it. It can include things, models, people and other resources.
- the project dimension (pointing downwards, right) is the vector product of the other two dimensions and represents reality deployed and ordered in time and space. Reality continuously evolves through the interaction of subject and object.

Pairs of dimensions form planes (see figure 1) that will subsequently be referred to as domains of experience: interactional, factual and conceptual (Nifle, 1986). The plane formed by the object and subject dimensions is the domain of affect and interactions: interactions between subject and objects. It is called the interactional and perceptual domain of experience. The plane formed by the project and subject dimensions is the domain of concepts and representations, and is called the conceptual and mental domain of experience. The plane formed by the project and object dimensions is the domain of actions and facts, called the factual and concrete domain of experience.

We will now answer our first question: What is the nature (the different domains) of students' experience during a laboratory session? A teacher who organizes a predominantly interactional experience may ask students to familiarize themselves with the apparatus, to contextualize the problems involved, to situate themselves (who does what, how do I feel about this), and to get a "feel" for a phenomenon. These are sources of perceptual and interactional experiences. This plane (the interactional domain) is orthogonal to the project dimension (figure 1), since it is not necessary for students to plan actions and organize tasks according to an objective. Next, with respect to the conceptual domain, students are asked to construct their own view and their own ideas, either in order to anticipate the analysis before carrying out an experiment, or to represent their results; they may spend most of the laboratory time debating on models and concepts. These are mostly mental or conceptual experiences. This plane (the conceptual domain) is orthogonal to the object dimension (figure 1), which reflects the fact that students do not need to interact directly with all the practical components of the experiment (roles of teacher and students, timing, apparatus, labsheet available, material constraints); they merely need to have an idea or image of these components. Finally, focusing on the factual domain, students are asked to observe phenomena, to perform the experiments and execute a protocol. They have to ascertain scientific facts, and experience that things happen. This is what we mean by factual or concrete experiences. This plane (the factual domain) is orthogonal to the subject dimension (figure 1), and indeed students do not need to appropriate the scientific issue under consideration in the laboratory session in order to execute a protocol or make observations. They can be guided in their observations and experiments. Although we have just considered them two by two (i.e. each two-dimensional plane), the three dimensions are to be found in every reality, or human experience. A human experience such as that of the student in a laboratory session can thus be deployed on this three-dimensional structure. Nevertheless, the teacher may choose not to consider all three and to emphasize one or two dimensions for learning, and thus focus on a single plane or domain of experience.

To get a feel for the three domains of learning experience as defined in this framework, let us take an example: imagine that you are a student in a laboratory session entitled "the intern anatomy of a frog". It can be a mostly interactional or perceptual experience for you if you are asked to touch and feel the frog, open it and freely draw what you see. You will probably remember your aversion to or curiosity for the experience. It does not necessitate any experimental planning: the interactional domain can be seen as the absence of the project dimension (figure 1). By contrast, it may be a factual, concrete experience if you are asked to follow dissection instructions. You will remember things such as the fact that you need gloves for this dissection, that forceps are useful, that frogs have no necks, that males are smaller than females, etc. Moreover, simply following the "recipe" does not require that you understand why: the factual domain can be seen as the absence of the subject dimension (figure 1). Finally, it can be a mostly conceptual or mental experience for you, if you are provided with a diagram of an open frog, a typical biological representation. You are told that the aim of the dissection session is really to identify and label each organ in the diagram. It is not absolutely necessary to dissect the frog, and you memorize the image of a diagrammatic frog rather than the body of the frog: the conceptual domain can be seen as the absence of the object dimension. In fact, in any of these lab sessions, you have a three-dimensional learning experience combining (figure 1) the factual, interactional and conceptual domains, as it is not possible to separate one from the other. However, our point is that each of these imaginary lab sessions would be dominated by one domain or another, depending on the instructions given by the teacher.

Other frameworks emphasize similar domains of experience. As we saw in the previous section, a group of researchers led by B. Bloom identified three domains of educational activities: cognitive (mental skills), affective (feelings or emotional areas) and psychomotor (manual or physical skills). By elaborating on this framework, Hostorm and Ottander (2005) used these three domains to analyze teachers' discourses on the aims of their labwork. Using another framework, Gooding (1992), when studying the way in which scientists construct their production, referred to the interaction of concepts, percepts and objects (the latter can be understood as perceived events or objects, Tiberghien et al., 2001), that is similar to the domains presented above. These works differ from ours in that here we present an integrated view of the three domains (figure 1) that reveals them in a new light. We define a domain as a plane determined by only two of three dimensions.

Empirical studies

We conducted two empirical studies. The aim was double: one the one hand, to illustrate how to use the proposed framework, and on the other to build tools to analyze labwork according to the three learning domains. In short, the data and the focus of their analysis are the following: (Study 1) 8 semi-structured interviews of teachers (practices in a lab session,) and (Study 2) content analysis of 15 labsheets (tasks given to the students). Both studies enabled us to answer our second question, since both provided us with teachers' acts in the form of discourse on practices (study 1) and written instructions (study 2). These teachers' acts were analyzed in terms of the domain of the students' experience. The question asked was: When the teacher acts in a particular way what does the student probably experience? Is this experience mostly conceptual, factual or interactional?

In study 1, after selection of the eight courses, we interviewed the teacher of each course and first agree on a particular laboratory session to be discussed. Such sessions usually lasted four hours. The interview, using the 'stand-in' technique (Clot, 2001), introduced a setting in which the interviewee (here a teacher) was told to imagine that the interviewer (here a researcher) was going to stand in for him or her the next day in the lab. The teacher was thus interviewed about the reality of the laboratory session for him/herself and the reality of the laboratory for the student as seen by the teacher. The interview was semi-structured, and included ad hoc questions that made it possible to determine what students had to do (according to the labsheet), what they did, the time allocated to the different parts of the lab, the difficulties encountered by the students and how the teacher might help them. In study 2, the content of 15 labsheets was analyzed. The labsheet was chosen as material for analysis because it is the students' first contact with the labwork and because it shows how they will engage in the lab activity (assuming that the teacher does not intervene excessively from the beginning). Tiberghien et al. (2001) underline that written instruction materials are the ideal medium for studying regular practices as they embody the decisions and perspectives that shape that practice. There can, of course, be considerable variation in the way the labsheet is used by the teacher, but we did not have access to that information in this particular study. We used materials from another study in the same research project, namely the CoPEX project that explores learning by designing an experimental procedure, (Girault et al. in preparation, Marzin, d'Ham, & Sanchez, 2007 ; Wajeman, Girault, d'Ham, Ney, & Sanchez, 2005). We used their selection of labsheets from the two first years at university, i.e. five in physics, five in biology and five in chemistry.

In both studies, the question asked is whether the labwork engages the students in a learning experience that is predominantly interactional, factual or conceptual, in cases where predominance can be identified. We used the coherenciel (figure 1) to categorize excerpts of teacher discourse (study 1) and paragraphs in labsheet (study 2). We ended up with a grid of analysis dividing each labwork into three parts: (1) the introduction, where students are given questions or tasks to engage them in the lab; (2) the central part, where they are given information on how to collect data and carry out experiments; and (3) the conclusion of the labwork, where they are given indications as to how to conclude (see table 1). One goal of our studies was to improve our tool to analyze current practices in labwork. Table 1 is the final version of this tool.

Table 1. Proposed grid of analysis.

The results of study 2 are presented in table 2. It shows that, from beginning to end (i.e. the three parts), 7 labsheets were predominantly factual, that only one was conceptual (in physics) and none interactional. Furthermore, our results (table 2) show that: the interactional domain is very seldom predominant in any of the three disciplines (4/45 parts in biology or physics labsheets) and the conceptual domain is rarely predominant (14/45 parts) elsewhere than in physics (10/14).

Table 2. Results from the 15 labsheet analysis.

The labsheet analysis and the teachers interviews lead to new questions and assumptions. First, some lab sessions seem to be organized in such a way that the students' experience is predominantly factual, interactional or conceptual. Our studies suggest two hypotheses: (1) the interactional domain is rarely predominant in any of the three disciplines and (2) the conceptual domain is rarely predominant elsewhere than in physics. It is to be noted that some lab sessions were not classified in the same domain from beginning to end, a session sometimes starting as factual and ending as conceptual, and another starting as interactional and ending as factual. At the level of a laboratory course, one may ask whether successive sessions should (depending on aims) go from a more interactional experience to a more factual one, to end with a conceptual part. We address this issue in the following section.

Discussion and Implications

The first question in this research concerned the nature of the learning experience that is organized by teachers in the laboratory. Our starting point was the three-dimensional structure of human experience based on the Theory of Sense and Human Coherences (Nifle, 1986) and our previous work (Ney, 2006). We then adapted this framework to the context of learning in the laboratory. This led us to characterize three domains of experience: interactional, conceptual and factual. It is assumed that all three domains are present in any learning experience but that some laboratory sessions may be dominated by one or the other domain. The second research question focused on teachers' acts that lead to different types of experience in the laboratory. This question was first answered on the basis of eight interviews of teachers and 15 labsheet analysis. In summary, in these analyses we found typical features that could be attributed to each of the three domains of experience. These analysis allowed us to illustrate how to use the proposed framework, and to refine tools to analyze labwork according to the three learning domains.

Moreover, this work led to a proposition presented in this section. We define three types of laboratory that have different functions. One of these proposes interactional/perceptual experiences, another factual/concrete experiences and yet another conceptual/mental experiences. We indicate the features of each type of laboratory, and also the possible consequences of focusing only on a particular type of laboratory. This is to argue in favor of series of laboratory sessions that target different experiences and do not focus on one of them alone.

The "interactional laboratory". We call an interactional laboratory a first type of session where students are typically asked to make comparisons and to ask themselves questions. They do so by exploration, by familiarizing themselves with apparatus, living things (in biology) or phenomena. They can use their senses to ascertain differences between their beliefs from past experiences and what they observe. The method they work with are not formal, and their actions are based mainly on their feelings and intuitions about the phenomena. The teacher uses this type of laboratory to enable students build an initial representation of the phenomena, and ask questions, which will later be elaborated into scientific questions. This laboratory makes it possible to build a common experiential ground shared by all the students in a class. The role of the teacher is to encourage students to make comparisons, to ask them questions, to introduce doubts, and to help them to formulate their own questions. The problem when focusing exclusively on this type of laboratory is the absence of the project dimension (figure 1). Students could have an image of science that lacks organization into scientific methods and procedures and clear objectives.

The "factual laboratory". This second type of laboratory is defined as follows: students make measurements, ascertain scientific facts; they follow experimental procedures that appear as a series of operations. Their confrontation with phenomena is guided. They note that certain things happen under certain circumstances. The teacher guides them to make observations and perform manipulations. He/she helps them to relate facts, to identify sources of measurement error, and to see causalities (when I do that, I get this). Some attention is given to bibliography, since students should know other experimental results. They learn about known procedures and methods that work. The problem when focusing exclusively on this type of laboratory is the absence of the subject dimension (figure 1); that is, students might not appropriate the question and might not relate the scientific questions to the procedure itself (Why do I proceed this way? How should I answer this type of question?).

The "conceptual laboratory". In this laboratory, students elaborate a model, verify a law, test the usefulness of a law or a rule. They may elaborate a concept or a representation. The experimental procedure plays a minor role in the session. It is a tool that serves the conceptual work or the modeling. The experiment may even be simply alluded to, with students working directly on data. The data analysis plays a larger part in the session. The experimental procedure comprises both theoretical elements (equations, diagrams, etc) and operations, and students are asked to switch back and forth from theory to experimental facts. They are asked to build a theoretical or conceptual image. The problem when focusing exclusively on this type of laboratory is the absence of the object dimension (figure 1): students might not relate the resulting models to material conditions and constraints.

To conclude, we have emphasized the problems involved in using only one type of laboratory. Hence, we propose to use all three types and to integrate the three into a series of laboratory sessions. For instance, especially for students who are not yet expert experimenters, a series could be designed as follows:
- an interactional laboratory session to get a feel for phenomena, to discover, and to explore,
- a factual laboratory session to make measurements, to ascertain facts, and to learn about known procedures,
- a conceptual laboratory session to conceptualize, to model, and to construct representations.

Interestingly, in a work based on several definitions of the term "experience", Coquidé (2003) proposed three similar modes of teaching in the laboratory. She defines an experience as either "experientiation", an "experiment" or a "validation-experience" leading to three corresponding modes of teaching. The difference here is that we focus on the domains of experience and characterize these domains in terms of a theoretical framework. By organizing several types of laboratory calling on different domains of experience, each with its own logic and its own demands, each requiring its specific form of teacher guidance, the teacher can tackle different learning issues. If contrasting situations are proposed, laboratory work becomes a privileged activity in which the different domains of human experience can be used for learning purposes. An open question remains for future work: what is the impact of the different types of laboratory on learning?

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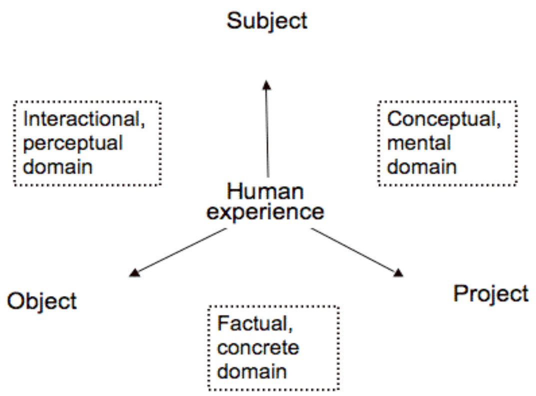

Figure 1. Coherentiel.

Table 1. Proposed grid of analysis.

Location	Interactional	Factual	Conceptual
Introduction	Compare with previous experience – Ask oneself questions – Explore	Characterize experimental apparatus – Make measurements – Ascertain facts	Elaborate a model – Verify a law or the domain of validity of a model – Define a concept – Build an image, a representation
Experiment	Familiarize oneself with scientific objects and phenomena – Tackle differences with common sense – A somewhat informal procedure. *Example: a list of equipment is given and students are asked to examine it and maybe make drawings or list comments.*	Operational protocol: series of actions, operations and parameter values *Example: the typical 'recipe' experimental procedure.*	The time spent obtaining data is reduced – the experiment is a tool used for modeling purposes – the procedure is dominated by instructions on how to represent, process and interpret data. *Example: a drawing, an equation or graphs that students are supposed to use to design their experimental procedure.*
Conclusion	Derive new questions, new directions for exploration – Build personal perception of objects and phenomena	Give values – Compare with theoretical or expected values – Indications on how to present data	Reflect on validity of model – Reflect on presentation of results – Defend conclusions drawn from data

Table 2. Results from the 15 labsheet analysis.

Scientific field	Introduction	Experiment	Conclusion
Animal biology	F / P	F	F
Genetics	F	F	F
Physiology	C	F	F
Bacteriology	F	F	F
Plant biology	F	F	-
Biochemistry	F	F	F / C
Electrochemistry	F	F	F / C
Inorganic chemistry	F	F	F
Organic chemistry	F	F	F
General chemistry	F	C	F
Fluid Mechanics	C	F / C	C
Electricity	F	F	C
Optics	P	P	P / F
Mechanics	C	C	C
Magnetism	C	F / C	C