How can we take into account student conceptions of the facial angle in a palaeontology laboratory work?

Patricia Marzin, Grenoble Informatics Laboratory, University of Grenoble,
46 avenue Félix Viallet, 38031 Grenoble cedex 1, France. patricia.marzin@imag.fr.
Erica de Vries, Laboratory of Educational Sciences, University of Grenoble,
BP 47, F-38040 Grenoble cedex 9, France. Erica.deVries@upmf-grenoble.fr

Abstract: This study investigates student conceptions of the facial angle as a way to attain understanding elements of the theory of human evolution. The chosen laboratory work involved determining the species of a human cranium, and students had to design and write down their own experimental procedure. Three versions of the laboratory work were carried out leading to different student productions. Three aspects will be presented in the present paper, which are related to the three conceptual difficulties that appeared in our a priori analysis: the importance of students' everyday knowledge of angles and of anatomy of human crania, the problem of knowing how many points make up an angle, and finally, the way in which students determined a reference system to construct an angle.

Context and theoretical background

This study is a preliminary to the development of Copex[(1)], an Intelligent Learning Environment that allows students to prepare experiments in biology, chemistry, geology and physics. In particular, the environment will scaffold the design of experimental procedures. The aim is to assist the teacher as well as the learners in present-day laboratory work practices. The development of Copex is based on task analysis (Clark, Feldon, van Merriënboer, Yates, & Early, 2006) by structuring the lab work activities in a task tree. At the top of the tree, a scientific problem is proposed, which generates tasks and sub-tasks. The actions at the lower levels of the tree represent the referent experimental procedures. The task tree structures the learning environment and can be used to conceive the laboratory work situation and to analyze student productions.

The present research aims at analyzing student productions when they have to write down an experimental procedure, as compared with an expert procedure, and at identifying the difficulties encountered by students. To investigate these questions, a team composed of eight researchers and four teachers has built and tested five laboratory works, with about three hundreds students in either the terminal level of the upper secondary school (ISCED level 3A-17/18 years old), or the first level at science university in Grenoble, France. Students had to find the procedure to determine the facial angle of several hominid crania. This value depends on the prognatism of the cranium, which is an evolution indicator: the more recent the species is, the more prognatism decreases and the more facial angle increases. The study was part of a design experiment for testing a new evaluation procedure of experimental skills in the French baccalaureat. In fact, the evolution theory makes up a very important part (one third) of the French terminal level biology curriculum.

This study is innovative to the extent that it deals with a new situation in laboratory work. Indeed, teachers usually suggest an experimental procedure to students to be followed, but students themselves almost never get to conceive it. An intelligent learning environment, which helps students and teachers design an experimental procedure, seems a promising approach to help students improve on the meaning of their scientific knowledge when doing laboratory works including communication between students.

Design experimental procedure for helping students to learn scientific knowledge.

Many studies have shown a lack of understanding by students in most experimental activities in laboratory work. The roles and functions of practical activities in sciences are presented in the official programs and instructions for school. In France, the introduction in 2001 of a test for the evaluation of the experimental capacities (ECE) in the baccalaureat has reinforced this role. The Committee on High School Laboratories (2006) defines practical work as: « physical manipulations of the real world substances or systems, interactions with simulations, interactions with data drawn from the real world, access to databases or remote access to scientific instruments and observations ». For Hodson (1990) "at the root of the problem is the unthinking use of the laboratory work". For Millar (2004), another problem relates to the way students interpret and explain data, facts, and relationships when they work in laboratories; ideas and explanations do not simply emerge from the data. Several other studies have shown that the application of a so-called 'cookbook mode' in practical work is not an efficient way to construct scientific knowledge (Tiberghien, 2001).

In the context of the experimental method, experimental procedures play an important role for putting theories to the test. Following Popper (1959), a theory is scientific only if it is falsifiable. Other scientists should be able to produce the same results, following the same procedure, in the same conditions. Designing an experimental procedure is therefore crucial to train students to the experimental scientific method. When students design an experimental procedure, they have to make decisions about the parameters they choose and also have to raise the issue of precision, which is the possibility for a measurement to be reproduced consistently. In doing so, students need to mobilize their own knowledge model. For the classroom context, we have translated falsifiability into three explicit criteria: relevance (give an answer to the scientific problem), reliability (reproducibility: obtain the same value) and communicability (can be used by another person).

To internalise the aim and the meaning of the experiments, we suggested that students first write down the detailed experimental procedure before executing it, to minimize the use of a cookbook recipe coming from an external point of view (Keys, 1999). The final objective of our research is to propose conditions and guidance to make the student autonomous with respect to experimental design and to allow a reflected implication of the teacher (Brousseau, 1989).

Some conditions to make students design an experimental procedure

The activity of designing an experimental procedure with the aim of obtaining data to solve the initial problem is composed of three steps:

- reflexion phase,
- writing phase (text, diagram, drawing, …) of the procedure,
- experimental execution.

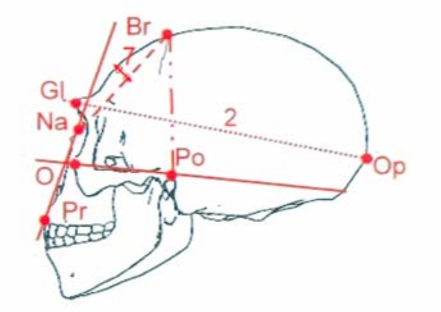
The steps depend on each other, and there is no linear order. In each step, students mobilise conceptions, which lead to choices, decisions and actions (Marzin, d'Ham & Sanchez, 2007). We looked at student conceptions when designing and writing down the experimental procedure for solving a palaeontology problem.

Students encounter difficulties when they design an experimental procedure: in writing a text, in correctly analyzing the situation and in referring to another situation that is probably more common for them. For example, students do not take into account the question of the precision (Marzin, d'Ham, & Sanchez, 2007). Students have to carry out tasks that are too numerous and too varied, including the control of precision of the measurements (Trochim, 2006), which is usually not allotted to them. Students have no opportunity to think about criteria in specifying parameters. To settle these difficulties, we conceived other situations and we defined conditions in which students design the experimental procedure. Our approach includes:

- a knowledge analysis combined with a task analysis,
- an evaluation of the distance between the tasks to be done and the knowledge to be learnt,
- a selection of the tasks that are allocated to the students, and those allocated to the teacher,
- an analysis to anticipate the difficulties that the students may encounter and a proposition of related feedbacks from the components of the environment,
- and finally the construction of a situation involving communication between students.

Expert knowledge about facial angle

In palaeontology, facial angle is defined as "the angle that is determined by the intersection of a line connecting the nasion and prosthion with the Frankfort horizontal plane and is used as a measure of prognatism" (medical.merriam-webster 1). The nasion (see figure 1) is the intersection of the frontal and two nasal bones of the human skull. Its manifestation on the visible surface of the face is a distinctly depressed area directly between the eyes, just superior to the bridge of the nose. The prosthion is the point located between the two central incisors. The Frankfort horizontal plane is "a plane used in craniometry that is determined the highest point on the upper margin of the opening of each external auditory canal (Po) and the low point on the lower margin of the left orbit (O) and that is used to orient a human skull or head usually so that the plane is horizontal" (medical.merriam-webster 2).



Na: nasion
Pr: prosthion
O-Po: Frankfort horizontal plane.

Figure 1. Measurement of the facial angle (source Naddam).

Designers of school curricula have simplified the formulation of the terms used for the points and do not mention the Frankfort plane (see Figure 2).

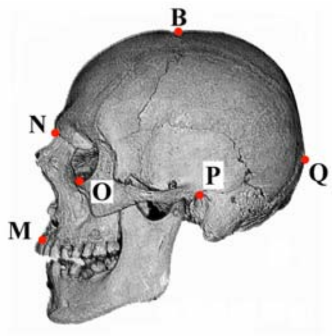


Figure 2. Facial angle representation in school curriculum (source: French Ministry of Education)

Student conceptions of an angle

In developing a teaching situation on prognatism, we were confronted by the fact that the determination of facial angle strongly builds on prior *mathematical* knowledge about points, lines and angles. In short, students need to know that 1) a point is an exact location in space, 2) a line is an infinitely thin, infinitely long, perfectly straight curve containing an infinite number of points, 3) exactly one line can be found that passes through any two points providing the shortest connection between the points, 4) if two lines in a two-dimensional plane are not parallel, there is exactly one point that lies on both of them, 5) an angle is the figure formed by two lines sharing a common endpoint, called the vertex of the angle, 6) an angle expresses the difference in slope between two lines meeting at a vertex without explicitly defining the slopes of the two lines. In her synopsis of the literature on the notion of the angle in secondary school, Vadcard (2002) retraces specific difficulties and three of these might play a role in the determination of facial angle.

Figures versus drawings

The first difficulty is related to the fact that an angle is a mathematical object. Note that a geometrical figure, as a mathematical object, has to be distinguished from a particular drawing. Pupils often confuse a mathematical object (figure) with a particular representation (drawing) of it (see also Duval, 1995). More specifically, in interpreting a graphical depiction, such as two lines meeting at one point, how does one selects the relevant features *prior* to knowing the definition of an angle? Pupils are influenced by the spatial-graphical characteristics of a drawing, they may, for instance, wrongly measure the length of two lines in order to evaluate the size of the angle. In looking for lines on the cranium for *constructing* facial angle, pupils may try to reproduce familiar prototypical angles found in textbooks and other pedagogical material, rather than looking for lines that are determined by characteristics of crania.

How many points?

More specifically, prior mathematical knowledge induces the strong expectation by students that the point of intersection of the two lines must correspond to a defined point on the cranium. Thus, three points suffice to construct an angle. However, in constructing facial angle, the requirements of experimental design, and more specifically the need for controlling variance, entails the definition of two lines: one for the base and one for the face. Each of the two lines involves defining two points, the so-constructed segments are then continued to construct the angle. Hence, the actual intersection between the two lines creates a fifth point, which may or may not coincide with one of the four points defined for constructing the two lines.

Choosing the reference

A final difficulty with the notion of an angle described by Vadcard (2002) is to consider an angle as the difference with the horizontal direction. In fact, thinking of an angle as the difference between two slopes is more complicated for students than considering it as the slope of only one line compared to the horizontal. In constructing the facial angle, students may omit to determine the second line, which corresponds roughly, but not entirely, to the horizontal. Although it is true that, on a cranium, facial angles are always acute angles smaller than a right angle (less than 90 degrees), occulting the base segment induces errors. The base segment has to be determined relatively to points defined on the cranium, and *not* relatively to the horizontal direction, because the latter depends on how the cranium has been preserved through time (with or without jawbone) and on how it is positioned in space (natural stand up position, lying down on a flat surface, hanging from a string, or fixed on a stick). Thus, students need to build a reference system that is internal to the cranium, independent of either the orientation of the cranium or the position of the lines forming the angle on a sheet of paper.

Research questions

In this context we are studying student productions with the following questions:
What are students' conceptions of the notion of an angle in a palaeontology laboratory work?
Why do these conceptions prevent students from successfully completing the task of building (the experimental procedure for measuring) the facial angle?
What are the recommendations for the Copex learning environment?

Methods

The data were collected during two school years, in 2005 and 2006. The sample was composed of 99 students in the terminal level of the upper secondary school (ISCED level 3A-17/18 years old), made of 5 groups of 18 students, and 1 group of 9 students, distributed in trinomials (33 trinomials in all). Each sequence lasted 90 minutes. All the student activities were recorded on audio and video numeric support.

The concrete activity proposed to the students was a palaeontology experiment where they had to design and execute a procedure for determining the facial angle of several homine crania. To solve this problem, they had to choose four characteristic points on a real cranium, and then project those points, materialized on the cranium with stickers, on a plan, in order to obtain two segments from which they could figure out the facial angle. They had at least two different real crania for doing several measurements. The facial angle value depends on the prognatism of the cranium, which is an evolution indicator. This angle is formed by drawing two lines: one horizontally from the nostril to the ear; and the other perpendicularly from the advancing part of the upper jawbone to the most prominent part of the forehead. To do that, the students used a paper handout that includes the description of the task and of the problem to be solved, some definitions, the explanation of the measurement method and work specifications. Students could write a text, plot the points on a drawing of a cranium drawn or draw a free schema.

To analyse the students' productions we looked at:

- choice of points
  - The number of points
  - The localisation of points on the cranium
- links between points
  - The direction of the lines (horizontal reference attendance or not)
  - The link between lines (drawing of features between the points or not, points of meeting)
- typology of terms used to name points (knowledge of anatomy).

The experiment was held in three steps (Study 1, 2 and 3) gradually introducing three criteria: relevance, executability (and reliability), and communicability.

Study 1: In a first exploratory experiment (12 trinomials), we looked at the way the students write an experimental procedure. Students had to find out and control the totality of the ten subtasks by themselves.

Study 2: A new situation (3 trinomials) was set up in which the teacher was in charge of making sure the projection of the points on the sheet was done in a perpendicular fashion (since this task doesn't focus on prognatism). We asked the students to write out their measurement protocol and, in order to assess the quality of their protocol, to use the following criteria: (a) it gives an answer to the scientific problem, that is measure prognatism (criterion of relevance) (b) it allows obtaining the same value of the facial angle for the same cranium (criterion of reproducibility) and (c) it can be used by another person (criterion of communicability). An additional criterion was used, although not explicitly: (d) the protocol must be effective for measuring the different crania of the sample (criterion of executability in the explored domain).

Study 3 (18 trinomials): we added a communication situation between students. Thus, they had to write down their experimental procedure for another group of students, who then had to perform the measurements according to the given procedure.

Results

In the present paper three aspects will be presented, related to the three conceptual difficulties that appeared in our a priori analysis. First, we describe the choice of points and how this choice is influenced by regular appearances of angles in textbooks and by prior everyday knowledge of anatomy of human crania. Second, we turn to the problem of knowing how many points make up an angle. Finally, we look at how students determined a reference system.

The influence of familiarity

As we said before, palaeontologists use criteria of precision, reproducibility and communicability in choosing points on crania. Moreover they possess a specialized lexicon for referring to those points. The students in our study spontaneously selected several points on the face, above the eyes, on the teeth and on the lower mandible referring to them with names used in everyday life (face, jaw, teeth) to designate parts of a cranium. These choices can be explained by the fact that the students have only approximate knowledge of the anatomy of crania. Furthermore, groups that did not have to confront their results with their pairs neglected issues of reliability (e.g. reproducibility, communicability).

We categorized the names for points in three categories: names for spatial positioning (82); names for points on the face (77); and names for indicating the horizontal direction (8). The first category contains mostly imprecise terms, such as “With the back”, “behind”, “above”, “in top”, “in the medium”, “in the centre”. Some more precise terms, such as “at the intersection”, “at the limit”, “with the birth”, are used only once by one group. These precise terms are more present in the third study, which most likely is a result of the obligation to send the experimental procedure to distant students.

The second category, for indicating points on the cranium’s face, the term most frequently used is "jaw", but without specifying if is the lower or the upper jaw. Most of the terms used belong to everyday language like “incisive” (8), “eyes” (7), “chin” (6), except “supraorbital pad” (10), which was used in the classroom in another lesson prior to the study.

In the third category, for indicating points on the cranium’s base, we found terms like “auditive hole” (4) and “ear” (3), and the technical term “occipital foramen” which was used only once. Therefore, the base direction received less direct pointing than the face direction.

Do three or four points make an angle?

An angle is the measurement of the slope between two directions, the face direction and the horizontal direction. Thus, the expert procedure involves determining two segments, each connecting two points. Table 1 shows the number of points determined by the students. In the first study, most groups determined only three points, as well as all three groups of the second study. In the third study, a large majority of students chose four points.

Table 1: Number of points chosen by groups of students in the three studies

Number of points	**0**	**1**	**2**	**3**	**4**
Study 1 (n = 12 groups)	1	0	0	10	1
Study 2 (n = 3 groups)	0	0	0	3	0
Study 3 (n = 18 groups)	1	0	0	3	14

The expert way of constructing the angle is by connecting two points placed on the face and two points placed on the base for the horizontal. The two lines do not need to intersect (see Figure 3), if they do not, their intersection will construct a fifth point. This fifth point does not need to be a defined point on the cranium.

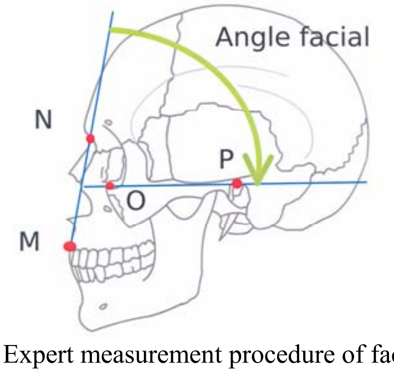
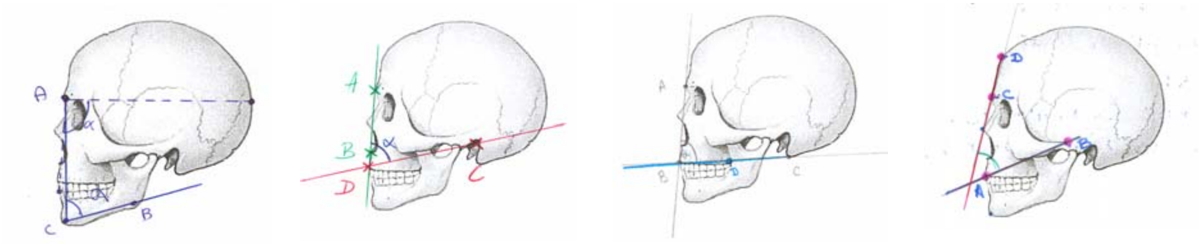


Figure 3. Expert measurement procedure of facial angle

Students’ construction of the facial angle will largely be influenced by their prior conception of facial angle. Figure 4 shows four types of ways in which students construct facial angle. On this issue, no conclusion can be drawn from study 2, since students only wrote a text and there was no cranium or angle representation. Not all students drew segments: nine groups in the study 1 and four groups in the study 3 didn’t represent links between points.



a) Three points (3 groups in study 1)

b) Four points with three on the face (11 groups in study 3)

c) Four points with three on the base (1 group in study 3)

d) Four points making two segments (2 groups in study 3)

Figure 4. Four examples of student's facial angle construction

Spontaneous conception

In the first type of construction, only three points make up an angle (Figure 4a). Students determine two points on the face and two elsewhere on the cranium. One of the points represents the vertex of the angle, one point remains unexploited. This representation was mostly produced in study 1, in which in addition very few students groups completed the drawing by actually drawing the lines (only 3 groups out of 12). In fact, this type of construction corresponds to a spontaneous conception of an angle as three points, one of which must be at the intersection of the two legs.

Intermediate conception

In study 3, students did produce four points as required. Even though they tried to use all four of them, they did not connect them two by two to construct two segments. In linking the four points, students followed two strategies, both still requiring one of the points identified on the cranium to correspond to the vertex of the angle. The two solutions involve either three points on the face and one point for the base (Figure 4b) or three points on the base and one point on the face (Figure 4c). These two constructions correspond to an intermediate conception in an attempt to combine a three-point angle conception with a four-point instruction on the worksheet. Actually, aligning three points out of the four points puts *more* constraints on the choice of points. Students managed to do this on one cranium, but these strategies would be unfeasible to repeat on other crania.

Expert conception

Finally, an expert construction identifies four points for independently drawing the two segments for the face and the base. The expert conception of an angle does not require a point corresponding to the vertex, that is the two segments do not need to have an intersection since an angle is a difference between two slopes. Only two student groups succeeded in constructed segments following the expert strategy (Figure 4d). Therefore, the actual intersection between the two segments creates a fifth point, which may or may not coincide with one of the four points defined before. But in this construction, there seems to be a problem related to the notion of horizontal reference for the base.

Determining the horizontal reference

Table 2 shows whether the points indicated on a drawing of a cranium are representative of the facial and of the horizontal directions (study 1 and study 3). Our criterion is that the points chosen on the face must be a good indication of the facial direction and that the points chosen on the other direction must indicate a relevant horizontal direction. Again, no conclusion can be drawn from study 2, since students only wrote a text and there was no cranium or angle representation.

Table 2: Indication of directions.

	No points for horizontal direction	Horizontal direction indicated
Study 1 (n=12 groups)		
No points for facial direction	3	0
Facial direction indicated	7	1
Study 3 (n= 18 groups)		
No points for facial direction	3	0
Facial direction indicated	3	12

Students are faced with a number of difficulties: they only have everyday general knowledge of the human head, they lack practice in the observation of crania, and they have an approximate knowledge of the cranium anatomy (name of various parts and form of crania), as they don't know which parts are specific of one particular cranium and which parts are found in all cases. Moreover, mathematical knowledge did not really help students to look for an angle as the difference between two slopes. In particular, the results show that it is difficult for students to build a horizontal reference. Out of 33 groups, 10 groups couldn't find points on a horizontal direction. Still, most groups in study 3 managed to build two correct directions, even if this was not necessarily accomplished with the correct points. For these groups, we can conclude that they actually understand the notion of facial angle.

Conclusion

This paper highlights various student strategies to construct an understanding of facial angle on a human cranium. Students mobilize knowledge and they make choices, design and write down experimental procedures to be executed by somebody else. External representations guide students regarding the required form of their experimental procedures. But sometimes prior conceptions of the mathematical object of an angle and about the anatomy of the human skull turn out to be obstacles, rather than aids, towards solving the palaeontology problem (measurement of facial angle of several crania with the aim of determining their position in the palaeontological scale). Students implement the model of human evolution, but they cannot have all the competences of palaeontologists. In particular, they find it difficult to name the cranium parts, because they don't have much knowledge about cranium anatomy. In successive adaptations of the lab work scenario, students were told to discuss their results and look at their data in comparison with standard data of palaeontologists. The study of student activities and productions showed that the gap between the students' procedure and the palaeontologists' one is far too important to be bridged. However, we take these results to be an encouragement for our strategy that involves students designing the experimental procedure for measuring some conceptual notion in an advanced domain. The act of making a notion operational reveals crucial student difficulties that would otherwise remain concealed. This strategy might prove to be productive in other domains.

Modelling laboratory work with task tree structures associated with the study of student strategies allows us to anticipate the types of support for experimental design that require implementation. The same task tree structure, when implemented in Copex, also enables to simplify certain actions. Moreover, it structures the teacher's work by suggesting laboratory work with the associated content, strategies and equipment. The use of a formal approach to model the student conceptions in a consistent way, for example with the cK¢ model (Balacheff, 2003), as well as the set-up of lab work situations which integrate this formalization, represent other research possibilities.

Endnotes

(1) COPEX: Designing the Experimental Protocols for Learning Experimental Sciences. From present classroom practices to a computer supported approach.

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Figure 1: http://svtolog.free.fr/IMG/pdf/craniometrie.pdf
Figure 2: http://eduscol.education.fr/D1118/BacS_SVT_2007_CapExp_Oblig_Suj05.pdf
Figure 3: http://upload.wikimedia.org/wikipedia/commons/8/8a/Angle_facial.png
Definition of facial angle: http://medical.merriam-webster.com/medical/facial+angle
Definition of Frankfort plan: http://medical.merriam-webster.com/medical/frankfort+horizontal+plane

Acknowledgments

We would like to thank the persons (teachers and researcher) who work with us: Daniel Devallois (lycée Présentation de Marie), Réjane Monod-Ansaldi (lycée Claude Bernard), and Eric Sanchez (Institut National de Recherche Pédagogique).
We cordially thank Nicole Millon for her second reading.
These studies were conduct within the CoPEX project, supported by the French ministry of education.