CONSTRUCTION OF STUDENTS' KNOWLEDGE IN RELATION TO A TEACHING SEQUENCE: HYPOTHESES ON LEARNING AND KNOWLEDGE

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This contribution presents analyses of teachers' and students' verbal and gesture productions in classrooms in order to construct knowledge involved in particular contexts. These analyses are based on theoretical positions on knowledge and learning hypotheses. In particular we assume that students' conceptual understanding of physics is constructed through acquisition of small elements of knowledge but not in the rational order given by the discipline; complex imbrications of association of elements can happen. Our methodology implies two scales of analysis. In the meso scale the decomposition of the productions are thematic and at micro scale we use "facets" - sentences meaning small elements of knowledge.

INTRODUCTION

This contribution is situated in a long-term perspective about students' knowledge construction in the framework of a teaching sequence, particularly during teaching sessions. The analysis of students' construction will be oriented in such a way that it can be related to taught knowledge: knowledge effectively involved in a given classroom. This perspective necessitates making explicit what we mean by knowledge, and our learning hypotheses. The methodology involved in the data analysis is closely associated with the theoretical framework. After presenting our hypotheses on knowledge and learning with the associated methodology we give two examples of analyses, mainly at the microscopic scale, and comments.

HYPOTHESES ON KNOWLEDGE

Our theoretical position on knowledge is based on Chevallard's work (1991). He dealt with knowledge by using the metaphor of life and ecology. Knowledge 'lives' within groups of people (a class in our case). The term "knowledge" has a broad meaning: it is not limited to content, but includes procedural components on the one hand and embedded epistemology on the other.

Within this framework, we introduce the concepts of "knowledge to be taught" and of "taught knowledge". These are constructs, and not obvious productions of educators or students. Knowledge to be taught is not the same as scientific knowledge. It is elaborated by the group(s) in charge of the official curriculum in reference to scientific knowledge. Knowledge to be taught and scientific knowledge differ also depending on the teaching level. For example, classical mechanics at middle school differs from mechanics at the end of secondary school, and this in turn differs from mechanics at university level, even though all of them refer to the same laws of physics. The concept of knowledge to be taught allows us to analyse the distance between these "knowledges" and the constraints which applied during their elaboration and which contributed to "shaping" them.

The concept of taught knowledge is necessarily associated to a particular class. It is a researcher's construct based on the discursive productions of the class (including gestures); it corresponds to knowledge staged in the classroom by the teacher and the students during a teaching sequence. This taught knowledge is a joint production of the teacher and the students. Both of them contribute to the specificity of the taught knowledge of a class (Sensevy et Mercier in press). Students' knowledge acquisition differs from taught knowledge; each student constructs his/her own meaning of the taught knowledge, even if common components of these meanings are shared in the class group.

Researcher's construction of taught knowledge

Taught knowledge is mainly ephemeral; only students' or teachers' written traces are permanent. Video recordings in the classroom keep this ephemeral verbal production permanent (at least partly). In particular, video recordings make available to the researchers the public productions (oral and gesture) of the teacher and of the majority of students. Our aim is to reconstruct taught knowledge without limiting it to a label denoting content. Teachers use these labels when they say, "today I used the inertial principle". To reconstruct taught knowledge we follow Bange (1992) in his interpretation of Grice; he makes a distinction between conventional and understood meanings. For a given sentence produced by a person during communicative interactions, on one hand, there is the conventional meaning that is independent of time, in the sense that it is clear what the sentence means. On the other hand, the understood meaning is dependent on the context. These two meanings are constructed from the same context. In a classroom context, a researcher can reconstruct several meanings. The taught knowledge is reconstructed by the researcher from: (1) disciplinary knowledge (mainly the knowledge to be taught, official curriculum, and textbooks and if necessary more advanced disciplinary knowledge); and (2) classroom practice; for example when the teacher proposes a formulation like "we'll not say force exerted by the system X on the system Y any more but force of X on Y". Consequently, the reconstruction of taught knowledge (conventional meaning) involves an external referent, which is disciplinary knowledge. On the other hand, the knowledge understood by a student in the classroom is reconstructed from the student's perspective; in this case the referent is internal, however this reconstruction necessitates taking into account the student's "history". Students' meanings and taught knowledge can be different even if the researcher reconstructs them from productions in the same time period and in the same classroom.

Framework of knowledge analysis

The chosen references for this analysis should allow researchers to reconstruct conventional meaning and students' meanings.

The first reference is based on the object of physics study: the material world. At the level of secondary school, the theories and models are not very sophisticated and their distance from the experiments or more generally the material contexts are not too large. We consider that modelling is a relevant reference in the analysis; more specifically we refer to three types of elements of knowledge: (1) conceptual, belonging to the theories, or (2) directly relative to experimental facts and more generally objects and events, or (3) dealing with the relations between the two previous types of elements.

The second reference, both epistemological and cognitive, is about personal or inter-subjective thinking processes that are involved in understanding the material world. We call these processes epistemic tasks (Ohlsson 1996). We limit our analysis to processes relative to the material world; they may be theoretical or descriptions of objects and events. In our definition of these epistemic tasks, integration of our approach to modelling leads to processes like describing, selecting, interpreting, calculating, making formal operations, and evaluating. We also have some complex processes like argumentation. In this text we do not present this analysis.

Size of elements of knowledge and learning hypotheses

The size of the elements of knowledge taken into account in the analysis is crucial: the choice could seem mainly methodological, but has consequences on the results and on the learning hypotheses. We discuss this point below.

LEARNING HYPOTHESES

All the hypotheses presented below are situated in a Vygotskian perspective; we state that physics learning will not happen without teaching and that the mediation of adult and of sign as well is crucial for learning.

Previous studies

Niedderer et al. (2005) has extensively studied learning pathways. In a recent review, he started by stating that learning processes will be seen as ‘conceptual pathways’ (Scott 1992), ‘learning pathways’ (Petri & Niedderer 1998), ‘conceptual evolution’ (Psillos & Kariotoglu 1999) or ‘conceptual development’ (Taber 2001) on a timescale of several hours. The idea is to follow students' constructions "during" the whole process of learning in more detail than in studies where mainly conceptual change from "before" to "after" teaching is examined. All these studies show that the evolution of students’ knowledge and the development of taught knowledge during teaching are different. Niedderer (2005) and others use the term “intermediary conceptions” to emphasize this difference. Dykstra (1992) proposed a good example of this difference by showing students’ evolution on the relations between force and velocity, with a teaching sequence (Figure 1).

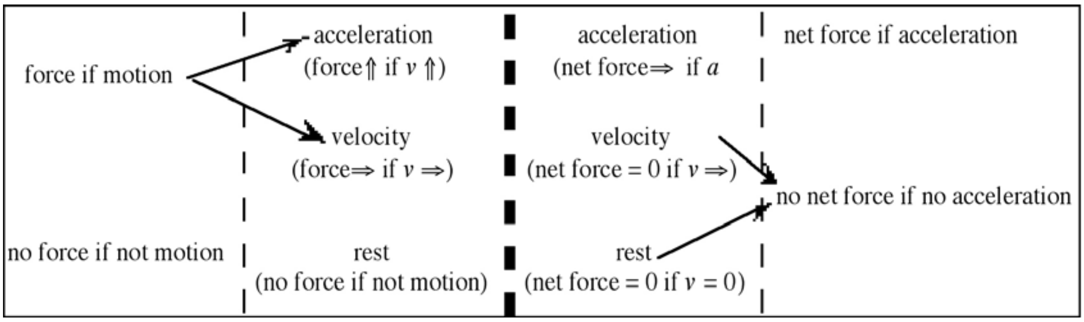

Figure 1: Students’ evolution on the relation between force, motion, and velocity (Dykstra 1992)

The students’ starting point is “there is a force if there is a motion”. The students explicitly construct a relation between force and velocity: “force increases if v increases” and “force is constant if v is constant”. Then they develop a relation between force and variation of the velocity with three cases: “force if variation of velocity”, “force zero is v is constant” and “force zero if v is zero”. At last, by relating the two cases, students construct: “force zero if v does not vary (or acceleration is zero)” and “force non-nil if acceleration”. This example illustrates an essential point of our hypothesis: the students’ pathways correspond to evolutions such that their knowledge is closer to the knowledge to be taught but is still incorrect from the disciplinary knowledge point of view.

This example illustrates that the learning pathway towards understanding a relation between concepts does not start by the learner's understanding each term of a conceptual relation, and afterwards the relation; the learner's construction of understanding involves simultaneously (or quasi simultaneously) the relation *and* each term of it; it does not follow the rational decomposition of disciplinary knowledge. So, as Dykstra (1992) and other studies show, the fundamental relation of the dynamic between force and acceleration (or variation of velocity) is very likely constructed from a relation between force and motion. This last relation, strongly anchored in the sense that "force is a cause of motion", is already constructed by the baby, maybe before language, and frequently mobilized in everyday life.

Our hypotheses

To investigate the learners' construction of knowledge, we propose to decompose intermediary conceptions into smaller elements of knowledge. We assume that new elements of knowledge integrated by learners are rather small. As shown by Küçüközer (2005), students can acquire an element like a single characteristic of the velocity of circular motion: modification of direction while value is constant. Such an element, and many others, will contribute to their understanding of the inertia principle (first Newton law). Conceptual understanding of physics is constructed through acquisition of small elements, but not in the rational order given by the discipline; complex overlapping of association of elements can happen. This position does not contradict the notion of obstacle if we take into account the methodology. As a matter of fact, if the study is done at a fine granularity level (small elements of knowledge) the researcher can reconstruct the students' evolution at this level along several sessions of the teaching sequence. Whereas if the study takes data only at different times of the teaching sequence, then acquisition of bigger elements of knowledge will appear (for example like the size of "impetus" proposed by McCloskey 1983). On the other hand our hypothesis may contradict the idea that learners acquire new concepts at once. We do not completely exclude this possibility but we consider it very rare.

We add another hypothesis: any one element of knowledge is not always learnt in the same way. The cognitive cost can be very different from one element to another, depending particularly on the set of elements in which it will be inserted. This condition on the set is essential because the meaning depends on the new links between elements of knowledge. Our study aims at contributing to better understanding of these different cognitive costs, to the extent that this difference has strong consequences on the teaching organisation. Teaching sequence duration, knowledge organisation, and pedagogical means should depend on the cognitive costs of learning the different sets of elements of the knowledge to be taught.

These hypotheses lead us to consider that taught knowledge favours knowledge acquisition if it involves repetition or re-use of new elements of knowledge.

Size of knowledge elements: methodological aspects

The analysis of classroom discourse is done at several time scales in order to construct the taught knowledge as well as the students' meaning.

At meso level (about 10 minutes), the taught knowledge is reconstructed on the basis of a thematic analysis (Tiberghien et al. in press). This analysis consists of dividing the discursive productions into units of about 10 minutes (Filletaz 2001). Each unit is constructed on the bases of (1) the structure of the discourse: the frontiers are frequently explicit, with an introduction and a conclusion (which could be a single word: well, now [we are going to another point] or a gesture: teacher erases the blackboard, changes position); and (2) a thematic coherence (see Table 3). Note that a macro scale corresponds to a structure in chapters or bigger parts, and most of the time it is identical to the written traces.

At the microscopic level (scale of seconds), the discursive productions are analysed with facets (Minstrell 1992) and Galili et Hazan 2000). These authors identify and catalogue elements of knowledge or reasoning that students seem to apply in various situations. These elements have the size of a sentence. Facets can represent alternative or scientific knowledge. In our studies, an effective utterance (or several utterance s in the case of verbal interactions) is associated to a facet to the extent that the researcher considers that they have the same meaning. The meaning can be either the conventional one or the speaker's one (student's meaning).

For the studies presented below, Küçüközer (2005) constructed a first list of facets in order to analyse students' evolution during a teaching sequence on mechanics at 11th grade. This list was adapted to analyse the classroom discourse of a teaching sequence on mechanics at 10th grade to reconstruct the taught knowledge: with the conventional meaning perspective. This list of facets, constructed a priori and a posteriori in an iterative way, includes sentences related to physics content and to students' proposals.

In the case of student' meaning, the discourse is transcribed and divided into several units at different scales. This division should allow us to study students' changes at short scale (about 10 seconds) and at larger scales: mesoscopic (minutes), and macroscopic (hours). This division is based on the structure of effective teaching content. At the larger scales (macro and meso) this structure is the school's or teacher's responsibility (sessions, classroom organisation). At mesoscopic scale the division corresponds to themes; it is the same as the division for taught knowledge. In this case we consider that the teacher's meaning and the conventional one are the same. At the shorter scales (minute or seconds), the division is based on students' activity, mainly carried out under their responsibility. An intermediate case, called "episode", corresponding to a question or a task statement, lasts about one to several minutes. This episode can depend strongly on the questions or on the students' initiative. At microscopic scale, the division, called "step", lasts for about half a minute, and depends on the way students carry out the task. Finally, still at micro scale, we analyse the discourse in terms of facets (see example below).

Note that our facet catalogue is structured in "large facets" corresponding to conceptual or procedural groups. These groups are:

- conceptual facets, that are components of concepts or relations between concepts (for example: When a system X is in interaction with a system A, we call the force exerted by A on X the action of A on X; moreover we sub-group by concepts (force, force-motion, force-variation of velocity, etc.);

- symbolic representation facets, that consist of the rules of construction of various representations like diagrams or vectors; for example the length of the arrow (force vector) represents the intensity of force;

- language facets, that consist of specific physics language like the standard expression associated to force: force exerted by X on Y;

- procedure facets, that consist of sentences related to a way of doing something like a standard symbolic representation, or finding the orientation of an action.

Two comments on our facets

Our way of using facets differs from Minstrell (1992) and Gallili et al. (2000) in two aspects. (1) We consider that facets are referents to analysis of discursive productions to reconstruct meanings (either conventional or in situation) and not knowledge. We infer knowledge after this first analysis in terms of facets. (2) The second aspect is more methodological. When the analysis of data in terms of facets is done, we carry on our treatment of facets *before* interpreting them in terms of knowledge or conceptions. Figure 2 illustrates the approach of Gallili et Hazan (type A), who group facets to obtain schemes or conceptions, and our approach (type B) that is illustrated below.

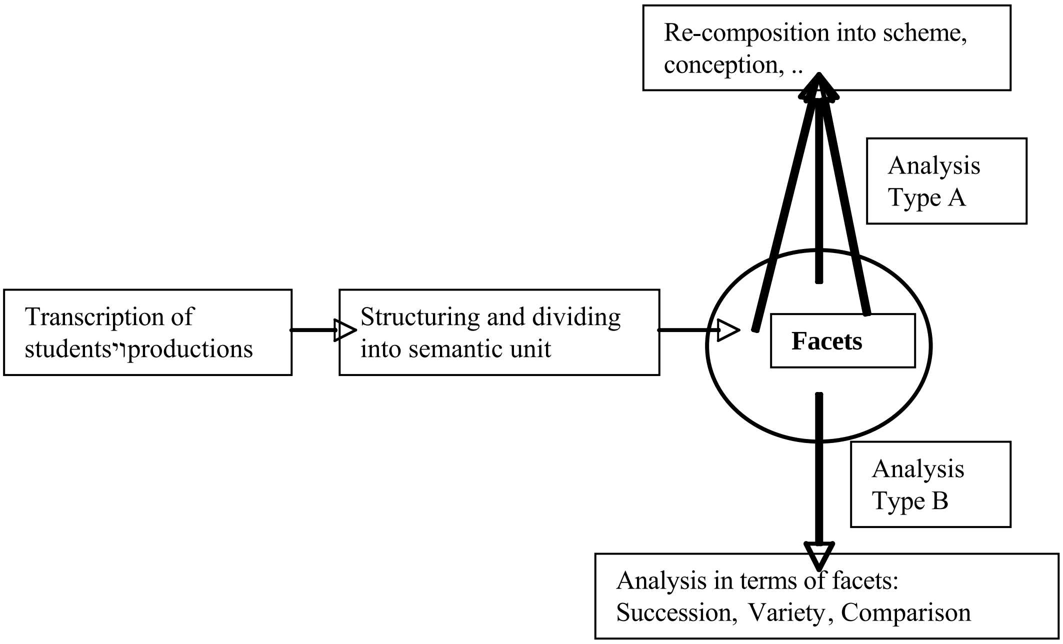

Figure 2: Analysis in terms of facets: type A recomposing into conceptions; type B: treatment at the level of facets before any recomposing into larger semantic unit

EXAMPLES OF ANALYSIS

We give two examples of analysis, the first concerns students’ meanings and the second the reconstruction of taught knowledge from classroom productions.

In these two examples, our analysis involves two scales: mesoscopic and microscopic.

Analysis of students’ production

This study is a part of Küçüközer’s PhD (2005). The collected data are mainly video recordings made during a teaching sequence on mechanics at grade 11. A research-development group (SESAMES) developed this sequence. Two cameras were used; one focused on the teacher and the other on two students, during the whole teaching sequence. During this teaching sequence, students working in pairs carried out a series of tasks. The analysis of students’ evolution is mainly based on student-pair’s work.

The example comes from the first task of part 2 of the teaching sequence devoted to dynamics (after part 1 on kinematics). The task statement and the first question are given in Table 1.

Throw the medicine ball up vertically and catch it.

1. Find and note the moment(s) where you exert an action on the medicine ball, indicate each time in what direction you exert this action on the medicine ball.

2. ….

Table 1: Task statement given at grade 10 and grade 11 in 'sequence Sesames'

We give the transcript of the first step of the first episode corresponding to the students' answers. The students work in pairs.

1 L: look at and note the moments where you exerted -*L reads*- // did you see the first question (?)

2 N : what (?) which part (?)

3 L: where you exert an action on the medicine-ball to begin you throw it using an upwards force

4 N : yeah after

5 L : to catch it we exert a downwards force

6 N : mum no an upwards force when we catch it's always an upwards force

7 L : - *L experiments* - upwards like that- *L experiments again* -

8 N : yeah but when we catch it you exert a force upwards as well

9 L : but you absorb – *L experiments*-

10 N : yeah well –*N takes the medicine-ball*- you make –*N experiments*- I am sorry I do not move

11 L : when you make that you move – *L experiments*-

12 N : yeah but yeah

In this extract N and L agree on the direction of the action (or force) when they throw the medicine ball upwards but disagree when they catch the medicine ball; for L it is downwards and for N upwards.

This oral production corresponds to three facets:

- The way in which A exerts an action on B gives an indication of the direction of the force exerted by A on B.
- When an object is in contact with others then it exerts a force on these objects.
- On noting the direction (orientation) of an action on an object one realizes (becomes aware of) the direction of one's own action on this object

The first facet corresponds to explicit verbal productions (force upwards and downwards, even if it is incorrect for L). L and N claim that there is a force when the medicine ball is thrown (line 3 for L and 8 for N who agrees) is caught (L: line 5, N: 6, 8). The second facet is inferred because we suppose that, for the students, there is contact between the ball and the hands when the ball is thrown. (Note that L did not maintain the direction of the action downwards; on his written note the force is drawn upwards). The third facet is rather similar to the first but involves the learner's perception; it corresponds to the actions of students who throw and catch the medicine ball to convince themselves and their partner (L 7, 9, 11; N 10).

The results of this type of analysis consist, for example, of the number of the most frequent facets used by a student during a teaching sequence (Table 2) or the evolution of the facets used.

	Number of the most frequent facets used by student L in tasks 1, 2, 3, 4
The way in which A exerts an action on B gives the indication of the direction of the force exerted by A on B.	13
When an object is in contact with others then it exerts a force on these objects	6
The force exerted by Earth on an object is a vector downwards	9
Earth always exerts a force on other objects	5

Table 2: List and number of the most frequent facets used by student L

For student L, we give the chronological list of facets related to the second Newton law (relation force-variation of velocity) involved during the teaching sequence:

- There is no link between the sum of the forces exerted and the variation of velocity
- There is no link between the sum of the forces exerted and the value of velocity
- The relation of dynamics is "if the velocity of the inertial centre of a system varies then the sum of forces which exert on this system is not nil"
- The vector of the sum of forces and the vector of the variation of velocity are collinear and have the same direction
- The relation of dynamics is "the vector of the sum of forces and the vector of the variation of velocity are collinear and have the same direction"
- The vector of variation of velocity is found by subtracting the two vectors
- For a vectorial subtraction, the vector "minus" has to be taken.

This chronological list shows three main points. First, L knows the inertia principle (he uses it correctly during task 1, steps 4.3). Second, at the beginning of task 3, L states a proposal that contradicts the second Newton law (relation F with acceleration or variation of velocity) and uses this relation correctly at the end. The evolution is obvious in this task but we consider that it is not only because of this task; several elements of knowledge were acquired for student L before this task. This comment introduces the third point: the importance of velocity in this construction of meaning of the second law; velocity is involved in different areas: vectorial calculus, relation between the results of a vectorial calculus and the variation of the velocity. The analysis leads us to consider that L constructs the second Newton law on the bases of the inertia principle and of the vectorial constructions of velocity and force. During task 1, L characterizes the type of motion and relates it to force; he also constructs relations between the types of specific motions and variation of velocity. This result leads us to stress the role of vectorial constructions of velocity and forces; these symbolic representations involve students' actions; they are used as reference in students' discussion and the tasks lead students to interpret them at conceptual level and also in relation to the material situation. The decomposition into facets show that small elements of knowledge which can seem uninteresting like "the vector 'instantaneous velocity' has a direction and a value" or "one finds the vector 'variation of velocity' by subtracting two vectors [velocity at two close points]" have to be learnt and play a role in conceptual understanding.

Note that another analysis of classrooms at grade 10 (see below) reinforces our conclusion on the importance of symbolic representations in conceptual learning.

Reconstruction of taught knowledge

The collected data are mainly video recordings made during a teaching sequence on mechanics for the part concerning dynamics (done just after kinematics) at grade 10 in two classes. One of the classes follows a teaching sequence designed by the SESAMES research-development group associated to our research team (called Sesames-seq). In the other classroom, the teacher individually developed the teaching sequence (called Pr-seq). Both sequences are in agreement with the official curriculum. Layal Malkoun is currently carrying out this study for her PhD (Tiberghien et Malkoun, in preparation).

At mesoscopic level the taught knowledge is reconstructed in themes (Table 3).

At microscopic level, we give an example of analysis in terms of facets, from a transcription extract during the second session of the observed class 'sesames-seq'. The teacher starts the correction of the same task as presented in the previous part (Table 2). (St A, B, C, D, E replace the student's name, St X means that from the video it is not possible to identify the students; start extract: 56:40). In this situation the teacher is just in front of teacher's table and the students sit and answer from their places.

P Well let us correct (?) first question note the moments where you exert [….] St A when do you exert an action on the medicine ball

St A when we throw it and when we catch it

P when we throw it and when we catch it when you throw the medicine ball the action of your hands or your action on the medicine ball how is it oriented (?)

St X upwards

P St A please answer

St A upwards

P upwards does everybody agree (?)

[…]

P And now St A when you catch the medicine-ball (?)

St A upwards

P it is upwards also does everybody see that (?) to prevent the medicine-ball from going downwards the floor what do you do with your hands you push upwards therefore in the two cases the action that you exerted when you throw up [the ball] and when you catch is an action upwards / do you checked it you correct [on your notebook]

[…]

P for each phase specify the velocity of the medicine-ball / St C when you throw what does the velocity do (?)

St C it increases

P it increases well you start from a velocity nil therefore you are going to make that velocity increases / St D when the medicine ball goes up what does the velocity do (?)

St D it decreases

P it decreases / St E what can you say about the velocity when it is stopped (?)

St E It is nil

In the analysis we distinguish the facets corresponding to an element of knowledge introduced for the first time in the class (called new facet) and those corresponding to elements already introduced (re-used facet). The following facets are involved

- When an object is in contact with others then it exerts a force on these objects (Re-used facet)
- Action has a direction (New facet)
- To prevent an object from sinking [into the ground] one exerts an upwards action on it (New facet)
- The value of the velocity can increase (Re-used facet)
- The value of the velocity can decrease (Re-used facet)

This type of analysis has been done for all sessions in both classes.

Time (min: sec)	Themes in class ‘sesames-sequence’	Themes in class ‘Teacher-sequence’	Time (min: sec)
	…………………..		
1:25	*Introduction of the general theme of the notion of force*	1. Effects of force on the motion of a object	18
18:44	1. Determination of phases of motion of an object, direction of action on this object, variation of velocity	*2. Interactions*	
10:41	2. Analysis of interactions for different phases of motion of an object (case of a medicine-ball)	2a. Interactions = A acts on B then B acts on A	14:33
4:41	3. Introduction of the force and its vectorial representation and of the principle of reciprocal actions	2b. Interactions at distance and contact interactions	4: 39
9:23	4 Using (exercising) force with and its vectorial representation from interactions (use of the full model of interactions)	3 Recalling of interactions	1: 31
5:14	5 Interactions: relations between a symbolic representation and one or several material situations	*4. Modelling actions by the forces*	
10:10	6 Representation of force (with direction) modelling an interaction (not the length of the vectors)	4a. Representation of force	9:15
30:31	7 Representation of force modelling an moving object	4b Measure of force	1:19
5:26	8. Introduction the inertia principle	5. Forces and masses	10:35
22:21	9 Compensation of forces exerted on a motionless system	6. List of forces and compensation (or not) of forces	45:21
7:55	10 Non compensation of forces exerted on a system of which the velocity varies	*6a Inclusion*: terrestrial attraction on an object in water	(2:27)
32:27	11 Inertia principle applied according to horizontal and vertical directions of the motion	*Total time: 1h 45*	
9:05	12 Influence of mass on the motion		
Total time: 2h48			

Table 3: Comparison of the succession of themes in two classes (grade 10) during the parts introducing forces until the introduction of the inertia principle. The bold line of the cells means a new session. When there is a general theme with sub-themes the duration is given by sub-theme. When there is an inclusion, the total duration is given and the duration of the inclusion is given between parentheses.

This set of facets is processed in different ways **before** an interpretation involving larger elements of knowledge. We present some examples. Table 4 shows the total number of new facets and re-used facets in the two classes. The higher number of facets in class “Sesames-seq” is due to the introduction of action and of a specific diagram before introducing force. We introduce the notion of continuity of knowledge: the rate of re-used facets divided by the total number of new facets. We make the hypothesis that a larger continuity for a similar teaching content favours students’ learning. Table 4 shows that the rate of continuity is rather similar in the two classes. An interpretation could be that teachers of these classes are very experienced and the classes are “average” with a similar social level.

Facets for the whole teaching sequence	Cl «Teacher-Seq.»			Cl. «Sesames-Seq »		
	Wh class	Group	Total	Wh class	Group	Total
New facet	49	1	50	65	21	86
Re-used facets	203	30	233	237	136	373
Continuity: Rate Re-used /New	*4*	*30*	*4,7*	*3,6*	*6,5*	*4,3*

Table 4: Introduction of new facets, re-used of facets and rate of continuity of knowledge (number or re-used facet divided by the total number of new facets) for the whole sequence in the two classrooms (Wh class means that the teacher and all the students work together on the same activity whereas ‘group’ means that students are working in pairs or in small groups autonomously

The comparison of the most used facets in the two classrooms (Table 5) shows similarities and differences. In the class “sesames-seq” the notion of action and its associated specific diagram are introduced before the concept of force, whereas in the other class, force is directly introduced. In both classes the association of contact between objects and action or force is very much emphasized. This emphasis is also shown in the independent study on the students’ evolution with the teaching sequence at grade 11 presented above.

A main difference between the two classes concerns the use of symbolic representations: the diagram system-interaction and the vectorial representation of forces are among the most frequent facets in class ‘sesames-seq’ and not at all in the other class. Table 6 makes the difference more apparent; the continuity for this group of facets is also very high for this class compared to class ‘teacher- seq’.

Large facets		**Cl.** 'teacher- seq'		**Cl.** 'sesames-seq'	
		Wh Cl	Group	Wh Cl	Group
Conceptual Action	When an object A is in contact with an object B it acts on it (there is a contact interaction between A and B)	2	0	**20**	6
	Earth always acts (attracts) the objects	1	0	**15**	5
Conceptual Motion	Motion of a point is rectilinear when its trajectory is a straight line.	**14**	2	8	3
	When the value of the velocity of a point does not vary the motion is uniform.	**13**	2	7	4
Conceptual Force	Earth always exerts a force on the other objects	**13**	1	2	2
	When an object is in contact with others then it exerts a force on these objects	12	1	0	2
Procedure **Representation**	Diagram system-interaction	0	0	**16**	**8**
	Force	6	1	13	11

Table 5: The most frequent facets in the two classrooms (Wh Cl means whole class organisation, group: students are working in pairs or small groups)

Group of facets « representations and units »	Cl 'teacher-seq'			**Cl.** 'sesames-seq'		
	Wh Cl	Group	Total	Wh Cl	Group	Total
New facets	5	0	5	17	2	19
Re-used facets	7	1	8	34	28	62
Rate %	*3,4*	*3,3*	*3,4*	*14,3*	*20,6*	*17*

Table 6: Case of facets relative to symbolic representation: rate of re-used facet compared to new facets

COMMENTS

This analysis of taught knowledge in terms of facets has to be complemented by an analysis at mesoscopic level. We do not develop this analysis here.

However, we would like to mention that these analyses for each scale are compared to the results of written questionnaires given to two sets of classes to which the two observed classes belong. These questionnaires were given before and after physics teaching on mechanics at grade 10. The first set is composed of 9 classes “teacher-sequence”, where the teacher designed the teaching sequence, and the second set is composed of 11 classes “sequence sesames” where the teachers followed the sequence designed by the research – development group (Sesames). The results show that, for a majority of questions, the two observed classes have the same behaviour as the set to which they belong.

We present some results very succinctly to show the differences in efficiency of teaching in a class depending on the type of notions; some notions are more difficult than others.

It appears that for questions dealing with the force exerted by Earth on a variety of objects (bird, swimmer, floating tree) the students of the two classes significantly evolve (between 30% and 46% of better answers after the teaching sequence than before) but students of class “Sesames-seq” give better answers. The percentage of correct answers at the end of the sequence to these questions is between 80% and 100% in this class whereas in the other class they are between 68% and 78%. On the other hand, for a similar question but formulated differently: “the weight” instead of “force exerted by the Earth on the object …”, the percentages are much lower for class “Sesames-seq”. The percentage goes down to 64% for class “Sesames-seq” whereas the class “Teacher-seq” obtains 74% of correct answers. All these results show that this concept of action (or force) of the Earth on objects can be learnt by a majority of students with a teaching sequence even if it is not easy; students have difficulty to accept the Earth action when the object is in water or a liquid or flies; students’ mastery of this notion also depends on its formulation (weight instead of force exerted by the Earth). Nevertheless this conceptual component can be learnt through adequate teaching.

A more difficult conceptual notion consists of recognizing that there is no force in the direction of motion when an object was thrown. Two questions dealt with that notion and the results show its difficulty. Even if there are better results for the class “Sesames-seq”, for one question less than 50% give the right answer (42% of correct answers and a progression of 29% of correct answers between pre and post questionnaires) and only 7% in the other class (“Teacher-seq”) with no progression. These last results are very similar to those obtained with two sets of 20 classrooms. The analysis of the taught knowledge shows that this notion was involved in the class “Sesames-seq”. This confirms how this acquisition is difficult as has already been stated in many studies. This case also shows the limits of the analysis in terms of facets. When we make an a priori analysis of these questions in terms of facets (those that should be used to answer them), it appears that only two or three facets are enough: “When an object A is in contact with an object B it acts on it” or “When an object A is not in contact with an object B it does not exert an action on it” or the equivalent with force: “When an object is in contact with others then it exerts a force on these objects”. We wonder why these simple statements, so often used in the classroom by the teacher and by the students (Table 5), cannot be used by all the students to answer the questions. The answer cannot be based only on the facet analysis but needs a deeper analysis of physics, and students’ knowledge. Moreover our analysis is carried out not only to interpret the difficulty but also to understand how about 30% of the students of the “Sesames-seq” class improved and very likely learnt at least partly this conceptual component of the Newton laws. We do not develop these interpretations; we just mention our direction of analysis. For the difficulty, we interpret it with causality. For learning, we make the hypothesis that the taught knowledge in the “Sesames-seq” class emphasizes descriptions and interpretations of motion and velocity several times, in particular the distinction between the phase of throwing where there is contact and the next phase. This division into phases of motion tends towards the basic causality that a change necessitates an action.

This difference of conceptual acquisitions in relation to taught knowledge illustrates the variety of cognitive costs to the extent that these notions were more or less involved in the taught knowledge.

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