



**EVOLUTION OF THE STUDENTS' CONCEPTUAL UNDERSTANDING IN THE
CASE OF A TEACHING SEQUENCE IN MECHANICS:
CONCEPT OF INTERACTION**

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ABSTRACT. This study aims to better understand the construction of the meaning of physics concepts in mechanics during a teaching sequence at the upper secondary school level. In the teaching sessions, students were introduced to the concepts of interaction and force. During this teaching sequence the models called "interactions" and "laws of mechanics" are successively introduced in the framework of tasks involving a variety of material situations. The hypothesis "students' initial knowledge on the verb "to act" is a founder notion, to the extent that its meaning plays a crucial role in constructing the concept of interaction" has been set. The research questions are: a) Does the verb "to act" plays a founder role in the construction of the concept of interaction? b) What are the other notions that intervene in the structured set of knowledge that students use to construct the concept of interaction in the teaching sequence? The results of the study show that, for the two students of the observed dyad, the notions of object and the concept of gravitation are simultaneously founder notions. Additionally, the two students of the same dyad who work together all along the sequence use different categories of knowledge and construct different meanings of the concepts.

KEYWORDS. Conceptual Understanding, Mechanics, Interaction, Newton's Third Law, Types Of Knowledge.

INTRODUCTION

Reviewing the related literature, a considerable number of studies are found on students' conceptions in Newtonian mechanics (see bibliography of Pfundt and Duit 2000). One of the main results of these empirical investigations of teaching and learning in mechanics was that few changes in conceptual understanding appear after teaching even at university level (Viennot, 1979; Clement, 1982; McDermott, 1984; Halloun and Hestenes 1985). Several articles focus particularly on students' understandings of Newton's third law (Terry & Jones, 1986; Brown, 1989). The findings commonly indicate that most students have a poor understanding of Newton's third law and of the force concept in general. The concept of force often remains a characteristic of objects (Terry and Jones, 1986); it is not a physical quantity characterizing interaction between systems. Many students don't believe that an inanimate and inert object can exert a force, for instance, they may think that a table does not exert a force on a book (Brown, 1989; Minstrell, 1982).

This study aims to understand the construction of the meaning of physics concepts in mechanics during a teaching sequence at the upper secondary school level. In the teaching sessions introduce to the concepts of interaction and force. During this teaching sequence the models called "interactions" and "laws of mechanics" are successively introduced in the framework of tasks involving a variety of material situations. In this study, the author focuses mainly on the concept of interaction.

In the following sections, first the theoretical framework dealing with the students' knowledge, then the teaching sequence and the categories to analyse students' knowledge will be discussed.

THEORETICAL FRAMEWORK

Understanding the students' construction of the meaning of physics concepts leads one to focus on the teaching situation and on the students' previous knowledge. The studies of other authors (Niedderer and Schecker, 1992; Richard, 1998, etc.) indicate that construction of meaning of concepts is produced by the interplay of the situation and the students' previous knowledge.

From a constructivist view of learning, students' previous knowledge is of central importance in learning. This leads us to carry out research into the role of students' initial knowledge in their construction of physics concepts using the approach of "founder notions". The "founder notions" approach, introduced by Tiberghien and Baker (1999), involves two different aspects: (1) the fundamental notions on the side of the knowledge to be taught; (2) founder notions on the side of the students' knowledge. The founder notions are supposed to constitute basic elements from which students construct new meanings to phenomena or new ways to solve problems. For these authors, these notions correspond to a set of structured knowledge. The "fundamental notions" are defined from an analysis of the knowledge to be taught. This analysis leads to consider that some pieces constitute "fundamental notions" that have to be understood by the learner in order that s/he acquires the knowledge to be taught. Consequently, it is necessary to analyse the knowledge to be taught and the students' knowledge. These analyses are based on several theoretical choices on modelling, on semiotic registers, and in linguistics.

Concerning modelling (Tiberghien, 1994, 2000), two main categories were used "the theory/model world" and "the objects/events world" involved in the verbal (oral and written and gestural productions). The following hypothesis is made: when a person or a group of people explain, interpret, or predict situation(s) in the material world, most of the time their productions entail observable objects or events, and/or physics parameters, and/or relations between them, which involves a modelling activity. This is why the aspects of the taught knowledge relative to

each of these two worlds are distinguished; in particular the theoretical aspects are made explicit as such to the students. This activity involves both the world of objects and events and the world of explanatory or theoretical frameworks, as well as models derived from these explanatory or theoretical frameworks (Tiberghien, 1994). The world of objects and events refers to all observable aspects of the material world, whereas on the other hand, the world of theories and models refers to theoretical aspects and elements of the constructed model of the material situations, in terms of various principles, parameters or quantities.

Concerning the semiotic registers (Duval, 1995), the learning hypothesis is that the relations between different semiotic registers of the same concept (natural language, schemas, graphs, etc.) favour the learner's construction of concepts.

Concerning linguistics, the distinction used by the linguists (for example see Ligozat, 1994) between the linguistic knowledge and the extra-linguistic knowledge is taken. The linguistic knowledge applies to sentences and their constituents; it is directly linked to language itself: syntactic knowledge, semantic knowledge and pragmatic knowledge. In this study, our analysis is based on the semantic knowledge, which takes the indication on the possible meaning for each word.

Consequently, to better understand the role of students' knowledge in the construction of meaning of concepts, different types of students' knowledge were considered:

- conceptual knowledge involving "concepts" and "notions" (which are not necessarily scientifically correct),
- knowledge on the material world directly involving objects and events,
- linguistic knowledge,
- knowledge related to the way to treat-interprets situations involving the different types of reasoning (causality, ontology).

Teaching Sequence

The literature shows how much the construction and the evolution of the meaning of the concepts depend on the teaching situations (Brousseau, 1986; Duit et al., 1998; Welzel and von Aufschnaiter, 1996). In this framework, the students' construction of meanings of the concepts was influenced by the interplay of many elements: physics content of the task, settings or objects and events at hand, material actions or interactions between students and between students-teacher. Each element of the situation is a resource of information for the students. During the construction, the use of all these elements depends on the student.

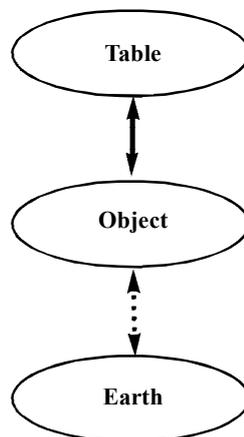
The teaching sequence was designed within a long-standing group in which teachers and researchers collaborate to develop "tools" for teachers. The main features of this design were to develop students' conceptual understanding and to give the possibility to interact with each other and/or with the objects and events at hand.

In generally, Newton's third law is introduced after Newton's first and second laws in teaching. For some researchers the force concept might be more effectively taught by emphasizing forces as interactions between objects (Brown, 1989; Reif, 1995, Savinainen, A. Et al. 2005). For instance, Reif (1995) suggested analyzing a physical system by describing both motion and interactions. In the framework of the teaching sequence, from an analysis of the knowledge to be taught it is considered that to construct an understanding of laws of mechanics, the concept of interaction is a fundamental notion. During this teaching sequence the models called "interactions" and "laws of mechanics" are successively introduced in the framework of tasks involving a variety of material situations.

From the studies on the students' linguistics knowledge, the verb "to act" is used in the text of model in this study. As a matter of fact, Guillaud (1998) showed that, on the one hand for a majority of students (14 - 15 years old) the word "interaction" is unknown, without meaning, and on the other hand the verb "to act" is known with its everyday meaning. In its everyday meaning the agent who (or which) acts should be a living being or a moving object. This meaning is different from the meaning given in physics (for example a pen can act on a table).

In the text of the model the concept of interaction is defined as the following: "in an interaction, when a system A acts on a system B, simultaneously B acts on A in an opposite sense; the action of A on B (written A/B) is in opposite sense to the action of B on A (written B/A)". These models involve symbolic representations: diagrams called "system - interactions" with a "set diagram" representing a system and arrows. As an example of the diagrams "system - interactions", figure 1 illustrates the case of an object is on the table.

Figure 1. A diagram "system - interactions" of "an objetc is on the table"



The double-sided arrows representing the interactions with a distinction between contact interactions (thick double arrow) and at distance interactions (dotted double arrow). It was emphasised that both objects participate in the interaction and that the interaction is symmetrical.

Research Questions

Taking the concept of interaction as a fundamental notion, it is necessary to study what the founder notions that allow the learner to acquire a sufficient meaning of interaction are in order that, later in the teaching sequence, the students use this meaning of "interaction" as a founder notion to acquire the laws of mechanics.

In the framework of this teaching sequence, the hypothesis that the verb "to act" is a founder notion to construct the concept of interaction has been set. The following research questions asked to guide the study:

- does the verb "to act" play a founder role in the construction of the concept of interaction ?
- what are the other notions which intervene in the structured set of knowledge that students use to construct the concept of interaction in the teaching sequence?
- how do these founder notions and students' previous knowledge intervene in the student's construction of the meaning of the fundamental notions?

Method and Samples

This study aims to understand the construction of the meaning of "in an interaction when a system A acts on a system B, simultaneously B acts on A in an opposite sense". In order to capture, to describe the entire process in as much detail as possible and to reconstruct the students' construction of the meaning, a case study methodology is used.

The data is collected continuously all along the teaching sequence at the first year of the French upper secondary school (15 years old students). One class was observed during instruction of a mechanics unit during 4 weeks. The students were encouraged to discuss and to verbalize their thoughts. Instructional activities included teacher presentation of activities, hands-on activities, and whole-class discussions. A dyad (F and L) is the subject of this case study. The dyad while engaged in hands-on activities and whole-class discussions were videotaped. All written productions of this dyad were collected. Field notes were taken based on classroom observations which focused on classroom discourse and activities.

The video sequences were transcribed. In this transcription observable activities (spoken words and sentences, gestures) are listed in chronological order for each student and teacher.

Data from multiple sources (field notes, transcripts of classroom discourse from videotapes, transcripts of dyad discourse from videotapes, and students' written productions) were used in relation to each other; this served to triangulate the data and to help enhance the credibility of the findings. For example, observation field notes and transcripts of classroom discourse used as secondary data sources provided a context for the interpretation of data. The dyad's transcripts and written productions were analysed. In this analysis, it is aimed to see what previous knowledge the students use and what information they take from the situation during their construction of the meaning of the concept of interaction. Two different examples are given here.

The first example comes from the first task of the teaching sequence. The following elements of the situation were taken into account by the author of this article: the experimental setting (a stone hanging from an elastic attached to a support) and the associated questions: "what is acting on the stone (?) and on what the stone is acting (?)", actions of the students on the stone and interactions between F-L and/or F-L-teacher.

To carry out this task the students use their previous knowledge, the teaching sequence does not introduce theoretical knowledge at this step. Some extracts of the dialogue are taken.

They read the questions and start to discuss on the question "what is acting on the stone". They begin to discuss:

F: What does to act mean?

L: which does something?

F: which holds which?

It is observed that L starts from his knowledge on language, the meaning of "to act" is "to do something". F starts from what he sees (the experimental device), the meaning of "to act" is "to hold".

For the two students the elastic acts on the stone. They touch the stone several times and they observe the experimental setting. For F, the elastic holds the stone; he uses the information coming from the situation. For L, the elastic acts on the stone because the elastic prevents it from falling; he uses a linear causal reasoning involving his knowledge on the material world and the information coming from the situation.

Later on, the teacher says to the whole students:

T: ... generally, everything can act on the stone in a visible or invisible way

F: The air, the air it acts / look when you make the air (he waves his arm)

L: There is the attraction, the attraction, there is the elastic, yes, otherwise the stone would be flying

For L, the attraction acts on the stone, he uses his conceptual knowledge. For F, the air acts on the stone, he uses his knowledge on the material world.

They begin to discuss on the attraction:

F: Not the attraction

L: Ben yes, if there is no attraction, it (the stone) would be flying the stone

F: Ben not the attraction, there is the heaviness of the stone/ the stone is heavy at the origin.

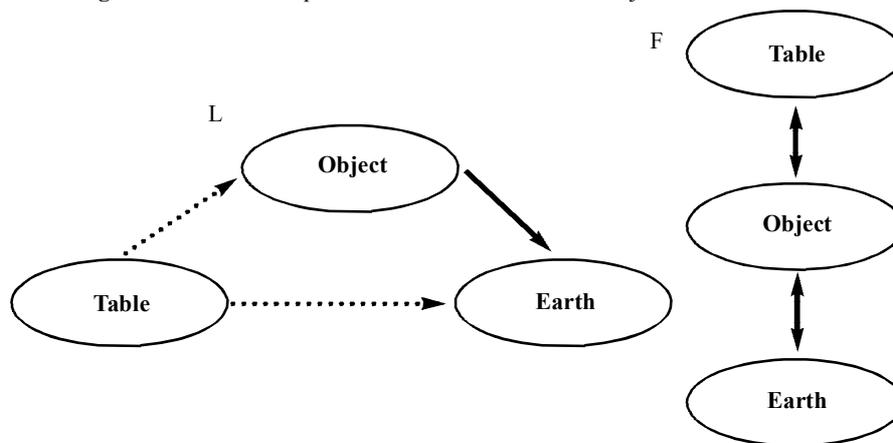
F, L use their knowledge related to the way to treat-interpret situations. L uses his conceptual knowledge and a linear causal reasoning: the earth acts on the object then the object doesn't fly. F focuses particularly on the property of objects.

The second example comes from the second task of the teaching sequence. Before this task, teacher distributed a sheet giving the text of the model. We take the following elements of the situation: the experimental settings (for example a pen is on the table), interactions between F, L and/or F, L, teacher and the physics content of the activity (the text of the model). This task asks to draw diagrams the called "system-interactions" for "an object put on the table". Here is an extract of the dialogue:

L: The earth acts on the table, the earth acts on the object too / the object acts on the table

F: But not the object, it doesn't act on the table, if there was no table the object would fall to the ground

Figure 2 : The written productions of F and L for "an object is on the table"



Analysis of their diagrams (figure 2) and their verbal productions shows that F and L use the elements of the situation and their previous knowledge differently.

For L, the earth acts on the table and on the object, he uses his conceptual knowledge of attraction, the meaning of "to act" is "to attract". To state that the object acts on the table, he uses his conceptual knowledge and a linear causal reasoning: the earth acts on the object then the object doesn't fly, and it acts on the table since it is attracted by the earth, consequently the object pushes the table. The meaning of "to act" is "to push".

For F, the object does not act on the table, the table acts on the object, because the table prevents it from falling. He uses his knowledge on the material world and the information coming from the situation. The meaning of "to act" is "to prevent from falling".

RESULTS

At a global level it appears that all along the successive tasks (12 tasks), the cognitive processes of the two students F and L are very different. It seems that L constructs the meaning of "in an interaction when a system A acts on a system B, simultaneously B acts on A in an opposite sense" better than F.

In particular, having a look at the evolution of the meaning of the verb "to act", the following differences between L and F are seen.

L associates it to "to do something (x3)", "to make move (x1)", "to prevent from falling (x3)", "to prevent from flying (x3)", "to attract (x12)", "to be pulled (x1)", "to tighten (x4)", "to pull (x1)", "to push (x4)", "to maintain (x1)", "to carry (x5)", "to make fly up (x2)", "to come back up (x1)", "to hold (x1)", "to make pull (x1)", "to keep (x2)".

F associates it to "to hold (x5)", "to tighten (x3)", "to prevent from falling (x1)", "to maintain (x6)", "to make fly up (x1)", "to push (x2)", "to make push (x2)", "to lean (x1)", "to slow down (x1)".

L associates it to 16 different meanings and he uses this verb 45 times. F associates it to 9 different meanings and he uses this verb 22 times.

During the construction of the interaction concept the way they use it corresponds to different categories of knowledge. L uses his linguistic knowledge, his knowledge on the material world, his conceptual knowledge whereas F uses his knowledge on the material world mainly and his conceptual knowledge very rarely. Again, there is differences between F and L in their ways to treat-interpret situations, to comment information taken from the situation, L uses his previous knowledge with a linear causal reasoning and when it is useful, a hypothetical reasoning. He wonders what will be the effect if the causal agent is removed, that is the change of the effect (state of the patient). F does not seem to use the linear causality. He comments on the information taken from the situation using his previous knowledge (particularly his knowledge on the material world) and taking the role of objects.

When looked at the types of the elements of the situation: generally F uses material actions and/or the interaction between F-L and F-teacher as source of information but not the physics content of the activity; L attempts to use all these sources. Concerning the physics content of the activity, F and L use much more the symbolic representations introduced in the model than the text. L chooses the systems and uses the symbolic representations more and more

efficiently. It seems that F draws the double arrows according to the didactical contract and not according to the meaning that he gives to the concepts.

Reconstructing the evolution of the students' meaning of "in an interaction when a system A acts on a system B, simultaneously B acts on A in an opposite sense" in relation to the other notions which were introduced, the analysis of the data shows that the two concepts, those of object and of gravitation also play an important role in the construction. For F and L, their initial meaning of "object" is not sufficient. From the two students' point of view at the beginning of the teaching sequence, the elastic or the stone are objects but the Earth is not. An object has small-scale dimensions in order to be handled. Two students show an evolution of the understanding of the concept of object. F's difficulty in understanding the concept of gravitation leads him to another difficulty in understanding the interaction between the earth and the systems and in the distinction between contact interactions (thick double arrow) and at distance interactions (dotted double arrow).

CONCLUSIONS AND DISCUSSION

In this article, it is attempted to understand and to analyse the students' construction of the meaning of the concept of interaction all along a teaching sequence in mechanics starting from the construction of the conceptual meaning is produced by the interplay of the situation and the students' previous knowledge.

From the approach of the "founder notions" and from the analysis, the founder notions students use to construct the concept of interaction in the teaching sequence have been attempted to determine. It is hypothesized that, in its everyday meaning, the verb "to act" was a founder notion to construct a physics meaning of the concepts of interaction. Our analysis shows that this verb "to act" is a founder notion. Finally, the linguistic aspect was important. The verb "to act" was used in a highly interactive based on dyad discussions. The students had opportunity to talk through their developing understanding, with the support of the different source of information on the situation.

The verb "to act" is not the single founder notion, the notion of object, the concept of gravitation, are simultaneously founders. The better understanding of the interaction concept necessitates the understanding of the notion of object and of the concept of gravitation. Moreover, the diagram "system - interactions" had a role in their understanding of the interaction concept. The representation provides support to the construction of deeper understandings (Ainsworth, 1999). This symbolic representation provides simultaneous use of multiple representations; students were encouraged to combine diagrammatic representations with verbal representations. However, this was not investigated in this study.

In order to understand this construction the decision to analyse each student of a dyad has been made by the author. It is shown that the cognitive processes of the two students F and L were very different. L constructs the meaning of the interaction concept better than F. The analysis of the data showed how much the use of the different physical and conceptual resources such as several categories of knowledge, the elements of the situation, influences the construction of the meaning. It is also shown that the "way of interpreting situations" prevents the students to attain the meaning of the concept of interaction. In conclusion, this study has provided further information on the finer differences between two students concerning the use of the different categories of knowledge and the elements of the situation. This information could help teachers to become more perceptive towards their students' learning approaches. On the other hand, this study draws careful attention to use of tasks which include various types of knowledge and resources.

This work put in evidence about various founder notions. Although this work came out from the point of view of the "microanalyses" of a set of situations, the results are needed to be generalized to a wider field. The author of this article believes that this kind of research, involving careful and detailed examination of both instructional design and considerations of the founder notions in specific areas of subject matters, is of considerable importance in the development of effective teaching approaches.

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