Misaligned Projections: an opportunity for learning

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Abstract

Misconceptions have always been an important focus of interest in physics education research. It is currently of great interest to the community to understand what role they play in learning and what opportunities they can provide. From the Coordination Class Theory (CCT), the conceptual development of two undergraduate students during solving a thermodynamic problem is analyzed. The analysis of the interview carried out during this task evidences a modification in their projections of the temperature Class, being misaligned at the beginning and aligned at the end. Moreover, the alignment of its projections has roots in its misaligned projection, which provides a context where new inferences and extractions emerge. That is to say, there is evidence of important potentialities that offer misaligned projections.

Key words: conceptual change, misconceptions, problem solving, coordination class, Thermodynamics

Introduction

Undoubtedly one of the topics that most focused research in the field of teaching physics has to do with misconceptions. This theoretical term is defined primarily as the ideas students have to describe or explain a specific aspect of an area, field, or phenomenon (Eaton, Anderson & Smith, 1983; Gardner, 1991). Students construct ideas of the world from an early age, sometimes corresponding to scientific ideas and sometimes not.

During the early beginnings of physical education research, it was argued that these misconceptions, which did not correspond to formal knowledge, were an obstacle to learning. Not only because they did not coincide, but also because they were ideas that were difficult to modify. The role of instruction for a long time was aimed at confronting these ideas or trying to replace them. That is why many studies in this field were dedicated to identifying which misconceptions should be replaced or removed. These types of studies focused for a long period of time on distinguishing incorrect student responses (Smith et al., 1992).

Fortunately, research took a turn when misconceptions were reconceived. In the 1990s, the field of conceptual development research grew strongly in this sense. Misconceptions were no longer an element to be eradicated or confronted in teaching, but were part of the first links of what began to be called conceptual change. Understanding these ideas as part of the construction of knowledge immediately led to the formulation of other types of questions in relation to this: What role do they play in students learning and how are they finally modified?

Several and important studies have made progress in how misconceptions contributes or not to conceptual learning. Problem solving resulted a privileged scenario to study how students' misconceptions evolve and the role they play as they learn. These kind of studies were oriented to address conceptual development in detail.

Andrea diSessa was one of the pioneers in understanding the process of conceptual change. He contributed with a theoretical development (Coordination Class Theory) and with empirical evidence of different ways in which a student coordinates the concept of force during a problem solving task (diSessa & Sherin,1998).

Witmann in 2002 used coordination class theory to understand student reasoning in wave physics during problem solving. He accounted about students' reasoning resources inappropriately linked to object-like models for waves (Witmann, 2002). Wagner addressed the transfer problem and contributed with details of conceptual development during problem solving tasks (Wagner, 2006). Levrini and diSessa also carried out a detailed analysis, for the case of the concept of proper time. They showed how data could be understood by means of Coordination Class Theory and how this approach highlighted the process of comparing, contrasting and conciliating students' conceptual views of this concept (Levrini & diSessa, 2008). More recently, Buteler and Coleoni revealed how conceptual development took place during problem solving for the case of buoyancy. In particular, they showed the role of epistemic resources within this approach (Buteler & Coleoni, 2016).

Computational resources were included on detail conceptual analysis too. In 2007, Parnafes studied how students' ideas of frequency and velocity evolved through the use of computational representations during problem solving. She was able to understand the role of this kind of as a support for conceptual learning (Parnafes, 2007). Sengupta et al. addressed a similar question for the case of linear momentum and using a video game. They showed how conceptual understanding evolves as students play a video game (Sengupta, 2015).

The PER literature offers many examples comparable to the ones described above. However these suffice to show how problem solving is an adequate activity to promote students' conceptual understanding. In this paper we are interested in better understanding the conceptual learning during problem solving. We will pay particular attention to the role of misconceptions in conceptual development.

Theoretical Framework

A Coordination Class is a model for particular kinds of concepts, among which are Physics concepts. The main function of a Coordination Class is to allow people to read a particular kind of information out of situations in the world. This reading takes place through specific processes and strategies. Many of the difficulties people have are related to the context and circumstances in which they carry out those particular strategies and processes.

The architecture of a coordination class includes two elements: *extraction* and *inferential net*. *Extractions* allow people to focus their attention on certain information of the phenomenon at hand. The inferential net is the total set of inferences people make to turn information read-outs into the required relevant information.

According to this theory, "using" a concept in different contexts may well imply retrieving different pieces of knowledge and/or articulating them in different ways. The particular knowledge and the particular way it is coordinated in specific applications of the concept is called a concept projection.

Typically, students exhibit two characteristic difficulties in creating a new coordination class: the problem of span, and the problem of alignment. Span refers to the ability (or lack thereof) to recruit and coordinate the elements of the class in a sufficiently large set of contexts in which the concept is relevant.. Alignment refers to the possibility of obtaining the same relevant information by means of different projections of the concept.

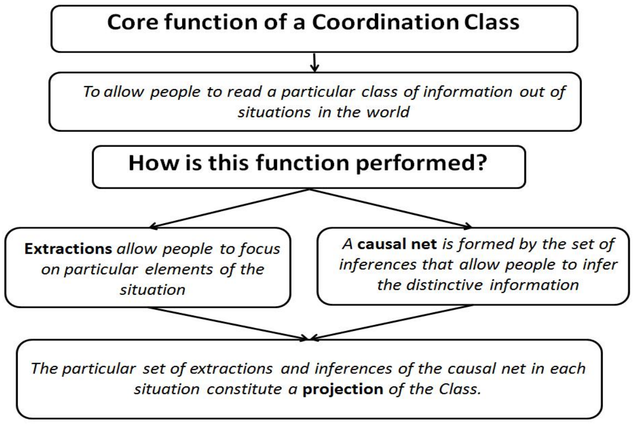

FIG. 1: Schematic representation of theoretical elements that constitute a Coordination Class. (Buteler & Coleoni, 2016)

Research Question

Considering the importance of student misconceptions in learning and the effectiveness of CCT in analyzing conceptual development, in this paper we will address the following research question:

-How to address a misaligned projection and what opportunities come from it?

Methodology

The study was carried out in a School of Physics in a Public University in Argentina. The two students interviewed voluntarily participated in the study. During the interview they discussed their decisions as they solved a problem involving a Carnot cycle. Both students had completed and passed a thermal physics course three months before the interview. The course is situated in the second year of a career in Physics and encompasses general topics on thermal phenomena, from heat, temperature, first, second and third law of thermodynamics up to a macroscopic description of entropy as typically presented in Searway's [32] or Resnik and Halliday's [33] textbooks.

Participants were video-recorded while they addressed the problem-solving task. Videos are useful for eliciting detailed information about students' reasonings. Instead of an individual interview as typically implemented in cognitivistist studies, a group interview was chosen for the analysis. This experimental setting provides different features at the same time. The interactive dynamic between students enables us to monitor how each participation evolves throughout the solving process. The reduced number of students allows to infer how conceptual development is happening.

The interview was a semistructured one. It was conducted by a researcher (one of the authors) who was not the students' instructor. The interviewer's role was to propose a task and, from then on, to follow students' reasoning. Elements proposed by Halldén in 2007 were considered for the interview: the interviewer's mission was to follow student's ideas and not to conduct their reasoning (Halldén, 2007). Interviewer's interventions were oriented at asking for a deeper explanations, checking understanding, or highlighting differences between students' reasonings.

A problem designed by the authors was proposed to the students. The problem was designed with the purpose that students explicit their ideas about thermodynamic processes (isothermal, adiabatic, reversible, irreversible, etc.). It enables us to monitor how their ideas evolve during problem-solving discussion.

The task consisted of analysing what happens with a monatomic ideal gas after it undergoes a particular process. The gas duplicates its volume during a free expansion, in which it does not exchange heat with the environment. The students should predict what kind of process is and what is the gas' final temperature. Figure , shows the problem statement.

Problem

A monatomic ideal gas with temperature T_0 ,pressure P_0 undergoes a free expansion from a volume V_0 up to a volumen $2V_0$. There is no heat exchange during the process.

- Choose the correct answer:
  a) The gas expansion is isothermal
  b) The gas expansion is adiabatic
  c) The gas expansion is isothermal and adiabatic
  d) Other: …………………..
- Find the final temperature of the gas.

FIG: Problem statement presented to students.

Since the gas does not exchange heat with the environment and does not produce any work, the internal energy must remain constant. Thus, the temperature does not change either. One could think that the transformation is adiabatic as well, because the no heat exchanging. However, special care must be considered to figure the final temperature out.

Since the gas does not exchange heat, it does not mean that it ends up on an adiabatic curve. It is important to remember that the free expansion corresponds to an irreversible process, thus the adiabatic equation of state is not valid in this case.

Results

The analysis was carried out on the audio-video data obtained during the interviews. It involved two distinct instances. A first stage consisted of an individual (one single researcher) revision of the videos as they were transcribed. In a second stage, these were reviewed by a research team as proposed by Jordan and Henderson. This collaborative viewing is powerful for neutralizing preconceived notions on the part of individual researchers and discourages the tendency to see in the interaction what one is conditioned to see or even wants to see (Jordan & Henderson, 1995).

We analyse in detail, from Coordination Class Theory, how the class "Temperature" develops. We want to account for conceptual development by identifying elements of the theory in students' discussions. Operational definitions of some elements of the theory are presented in table I. In particular, we want to identify the role of misaligned projections during the conceptual development.

The analysis is organized in two fragments. First, students conclude that the process is both isothermal and adiabatic (fragment 1). Then, they convince themselves that the temperature does not change during the free expansion (fragment 2).

TABLE I: Operational definitions for extractions, elements of the inferential net and projection.

Operational criteria to interpret data in students' verbalizations		
Knowledge element	**Operational criteria**	**Some examples**
Extractions	*- They refer to specific traits in objects in the situation* *- They are directly read from the context or statement*	*- Gas does not exchange heat with environment* *- The expansion is free*
Elements of the inferential net	They involve abstract elements such as concepts or physical laws. There are usually expressed in the form of if-then statement	*-Temperature remains constant* *- The velocity of particles is always the same, so the temperature does not change.*
Projection	It is directed to producing a concept-distinctive information	*If delta Q is zero, the gas does not work and the first law is always valid, the temperature must not change.*

1. **A misaligned projection: "The process is isothermal and adiabatic"**

In the first minutes of the interview, students arrive at the conclusion that the process is isothermal and adiabatic. The following snippet shows the students' dialogues that enable us to infer their reasonings. Students are identified with the letter A and B respectively.

$\mathbf{S_1}$ [2:00 min]

1. A: I think it's isothermal...

2. B: We know it's adiabatic...the statement is saying it: "it does not exchange heat". We should see if it does work...

3. A: It's a free expansion, so it doesn't do work...

4. B: You're right, it doesn't do work on the environment..So it's isothermal too.

5. A: Right..

6. Int: So, you're saying that the transformation is isothermal and adiabatic. It's adiabatic because the gas doesn't exchange heat, and it's isothermal because there is no work. Now, I have a doubt: if the gas expansion is both (isothermal and adiabatic)...in a P-V diagram, where is going to be the final temperature? We know, as you mentioned before, that this is an irreversible process and the initial and final points are the only of equilibrium. So, the final point is on an adiabatic or an isothermal curve?

In this fragment is possible to identify the conceptual path that students follows to arrive at their answer. Two students' extractions are identified (*"...it does not exchange heat…"*; *"It's a free expansion..."*) that let them to infer new information on the situation (*"...it's adiabatic…"; "it's isothermal too…"*). This kind of analysis enable us to infer some ideas that they are regarding to choose this option. First, they consider that when there is no heat exchange the process is adiabatic. Second, the application of the first law of thermodynamics enables them to infer that there is no change of temperature. For this, they consider the process as an isothermal as well. This inference is the first step before the projection of the Class Temperature. Until here, students deduced the type of transformation done by the gas. Figure II summarises the elements of the class during this fragment.

Over the final of this snippet, the interviewer poses the problem to students about what is the final temperature. He takes students' inferences and he makes them dialogue with each other on the problem of temperature. The interviewer conflictuates their inferences to present to students possible dissonances among them. This is an important point in the interview. The conflict presented to students makes them reconsider their ideas and review their reasonings to address the temperature problem. In a first approximation, it seems like students make a misaligned inference when they say that the transformation is isothermal and adiabatic simultaneously.

Following fragments show how students address the problem of the temperature of the free expansion. Their first inference is not enough to reach a unique and consistent answer to the temperature problem. Thus, students must resort other set of ideas.

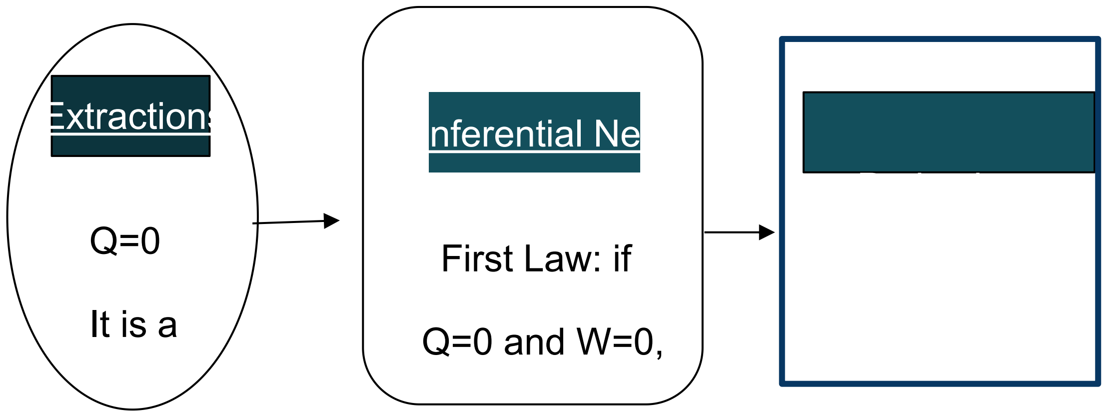

FIG II: Synthesis of Class in fragment 1.

2. Re-Projecting the Class: "The temperature of the gas remains constant"

During this fragment, students convince each other and themselves that the temperature of the gas does not change during the free expansion. They address the problem from two approaches: a microscopic view and throughout the first principle of thermodynamics.

S₂ [5:00 min]

1. *A: Isothermal implies that the temperature doesn't change, isn't it?*

2. *B: Right, but if the process is isothermal and adiabatic at the same time...Imagine that you plot the initial and the final state. If it was isothermal, the final point is right here (*she points on the graph*)...but if the process was adiabatic the final point ends below it.*

3. *A: Right…*

4. *B: Isotherms and adiabatics don't intersect each other, do they? Mmm, I don't know...If I have...mmm, no, I don't know…*

5. *A: I have a doubt...If I already know the temperature at which the expansion is made...But, I don't..*

6. *B: Right… from the kinetic theory point of view, I don't find any reason for a change in temperature.*

7. *A: There are less number of collisions for me...*

8. *B: It isn't because the number of collisions...it is because the velocity and it doesn't decrease with collisions...The collisions are elastics.*[1]

[1] This reasoning is expressed incompletely during the interview. The student argues that the speed of the particles does not change because it is assumed that the shocks are elastic. They do not use this argument to determine that there is no work. It should be clarified that, in addition, there is no moment transfer to the

9. B: The first principle is always valid, right? regardless of whether the process is reversible or irreversible. So, if the gas doesn't exchange heat, delta Q is zero. The gas doesn't do work. So the variation of the internal energy is zero, therefore delta of temperature is equal to zero.

10. Int: What happens with the adiabatic curve?

11. A: I don't know...The problem is saying that there is no heat exchange…

12. Int: How the adiabatic curve is defined?

13. B: Ohh! Right...It's defined from the state function which is valid only for reversible process. So it's not true that the gas would end up on this curve. And the first principle is always valid!

14. Int: so you say that the final temperature is the same that the beginning?

15. *A&B: Yes!*

Students address the problem of the temperature of the gas during this snippet. Once they decided that the process was isothermal and adiabatic too, they started to deduce the final temperature of the gas after the free expansion. They encounter the problem of having two final temperatures for the process in simultaneously: one on the adiabatic curve and the other, on the isothermal curve. For this, they need to expand their set of ideas.

A set of new inferences enables them to deduce what happens with the temperature of the gas. Two approaches are identified during the fragment. On one side, they propose a microscopic view to address the problem of the final temperature. Student B infers that there are no reasons to think that the particles' velocities change (turn 8). On the other side, there is a recall of the first principle of thermodynamics. Over the final of the snippet, B claims that if there is no heat exchange and there is no work done neither, it would not be a change of the internal energy. One important thing to highlight is the way in which they evoke the first principle this time. They notice about the irreversibility of the process (extraction of the situation) and it is considered in their reasoning. It is possible to observe that the first principle is an important argument for them because it is valid in reversible and irreversible contexts (turn 9). Thus, these new inferences enable them to affirm that temperature remains constant which complete the projection of the Class Temperature (turn 9). Figure III synthesizes the projection of the Class up to here.

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particles by the walls since it is a free expansion. However, this argument is enough to make them suspect that the temperature should not change.

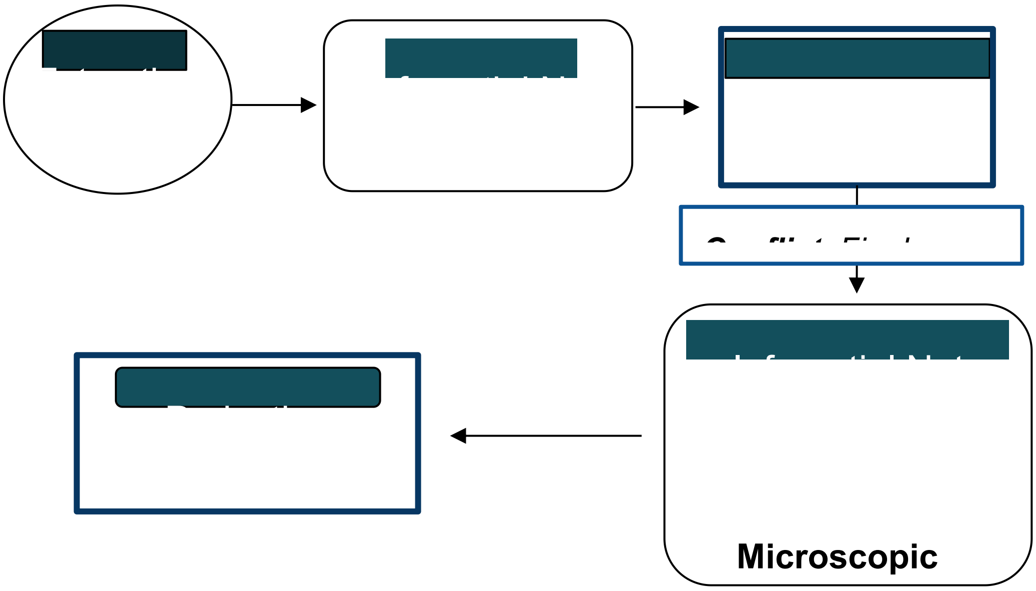

FIG III: Synthesis of Class projection in fragment 2.

It is possible to observe that the misaligned projection became aligned with the conflict proposed by the interviewer. Students expand their set of ideas as a result of the problem proposed. They incorporate new ideas (as the microscopic view) and refine older ones (as the first law) to convince themselves about the new projection.

Two things are important to highlight from the interview. On one side, a misaligned projection is overcome throughout a new problem, a new conflict. The learning process is developed throughout a problem, a conflict, rather than giving the “right” answer to correct students’ misconceptions. Something analogous was presented in previous research (Velasco et. al., 2019) were the learning process is developed throughout comparing misaligned projections. Thus, it has been shown that incorrect reasoning is an important input for learning to take place.

On the other side, conflict allows students not only aligned their projection but become it stronger. The misaligned projection makes them resort to new ideas, expands their inferential net, analyzes the validity on the particular context and create a hierarchy structure of their arguments and inferences.

Discussion

Coordination Class Theory (CCT) results a productive theoretical framework to follow students conceptual development. As previous research conclude, it provides a frame where the misconception is reconceived. The present work was oriented to analyze the role and potentials of misaligned projection during problem solving. A study case of group problem-solving discussion was analyzed throughout the theoretical frame of CCT.

How to address a misaligned projection and what opportunities come from it?

Video-record data was analyzed in order to rebuild the conceptual development of two undergraduate physics students. They discussed about the final temperature of an isolated ideal gas free-expansion for several minutes. The analysis of the interview enables to identified some elements of the CCT and reveals important results about the research question.

In a first instance, students complete a misaligned *projection* when they concluded that the process was isothermal and adiabatic. They *extract* for the situation the no heat exchanging between the gas and the environment, which is enough for them to affirm that the process is adiabatic (S_1, turn 2). On other side, they apply the first law of thermodynamics to *infer* that the internal energy does not change (a free expansion does not do work), thus, the temperature is constant and the process isothermal too (S_1, turn 4). This *projection* is misaligned if one regards that adiabatic or isothermal processes are reversible. The free expansion is an irreversible process and the only thing that one can says is that the temperature is constant.

Interviewer conflict students asking about the temperature of the final state of the gas. Considering their projection, the final temperature could have two possible values. This conflict makes students to review their ideas and incorporate new ones to address the problem. First, they evoke kinetic theory, a microscopic view, in a try to deduce the final temperature of the gas (a new *inference*) (S_2, turn 6). It enables them to suspect that there is no reasons to think that the temperature will change. However, they resort to a stronger argument.

They recall the first law of thermodynamics, but this time they note that it is valid for reversible and irreversible process (S_2, turn 9). This contextual information makes them assign a special importance. They consider this inference from the first law in the highest level of hierarchy respect the others inferences. This *inference* makes the students finish deciding that the temperature is not going to change. Moreover, they rule out that the temperature ends on the adiabatic curve because they consider that it is defined by the state function, which is not valid for this case (S_2, turn 13). In this way, it can be observed that the students project the class in an aligned manner after the conflict raised by the interviewer.

Two interesting aspects are found from the analysis. On the one hand, it is important to highlight how, starting from a misaligned projection, it is possible to arrive at an aligned projection. Contrary to what one would think, the projection is not aligned through an explanation that "corrects" the ideas of the students. On the contrary, the projection becomes aligned by presenting to the students a problem or context where it is conflicted. It is not the interviewer who aligns the students' projections, but they do it themselves through problem solving.

On the other hand, it is important to highlight the opportunities generated by a misaligned projection. From the analysis of this work it can be observed how a misaligned projection that is conflicted allows students to: expand their inferential network, reconsider already thought ideas and discover new aspects, establish hierarchies between different inferences and integrate the different reasonings. These potentialities not only help to align a projection but also strengthen it.

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