LABATORIALS AND REFLECTIVE WRITING FOR A BETTER UNDERSTANDING OF DYNAMICS IN HIGH SCHOOL

Joseph El-Helou

A Thesis in the

Department of Physics

Presented in Partial Fulfillment of the Requirements

for the Degree of

Doctor of Philosophy (Physics)

At

Concordia University

Montreal, Quebec, Canada

October, 2020

CONCORDIA UNIVERSITY

School of Graduate Studies

This is to certify that the thesis prepared

By: Joseph El-Helou

Entitled: Labatorials and Reflective Writing for a better understanding of dynamics in high school

and submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY (Physics)

complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the final examining committee:

Dr. Alisa Piekny	Chair
Dr. Mark. Lattery	External Examiner
Dr Tanja Tajmel	External to program
Dr Mariana Frank	Examiner
Dr. Pablo Bianuci	Examiner
Dr. Calvin. S. Kalman	Thesis Supervisor

Approved by:	Dr. Valter Zazubovits	Graduate Program Director
	Dr. Pascale Sicotte	Dean of Faculty

Date October 23, 2020

ABSTRACT

Labatorials and Reflective Writing for a Better Understanding of Dynamics in High School

Joseph El-Helou, Ph.D.

Concordia University, 2020

Decades of research show that introductory physics students struggle to learn Newtonian concepts of force and motion. Conventional lecture method of instruction has been unable to improve students' ideas and attitudes. This study examined the impact of combining Labatorials and Reflective Writing on high school students' knowledge of Newtonian dynamics.

Participants are 210 secondary 5 (grade 11) students, from three private schools in Montreal, who took a physics course during 2017-2018 and 2018-2019. Their ideas and opinions about forces and learning physics were investigated, prior to and following the study, with: (a) the Discipline-focused Epistemological Beliefs Questionnaire; (b) the Force Concept Inventory (FCI); (c) a concept map focused on the relations between force and motion. Pre- and post- semi-structured interviews were conducted with 12 participants. The post interview required students to analyse a hands-on experiment about the two-way motion of a fan cart. Data was also collected from participants' teachers throughout the duration of the study.

Results from the FCI indicate a medium gain as calculated by Hake (1998) which is similar to those obtained when Interactive Engagement practices are used in teaching physics (Hake, 1998). The interviews with students as well as feedback from teachers showed that students preferred the combination of Labatorials with Reflective Writing to traditional labs. Preliminary analysis of concept maps completed in the post-test to those in the pretest indicate that students better connected concepts related to forces and motion. The gathered data and interviews indicate that the process of combining Labatorials with Reflective Writing improves students' knowledge of the subject as well as their attitudes towards learning it.

ACKNOWLEDGMENTS

Foremost, I would like to express my sincere gratitude to my advisor Prof. Calvin Kalman. Throughout my PhD work, he provided excellent follow up and advice. He is an excellent strategist who mastered making the best of situations and of people. He is a great motivator who elicited the best in me. He always provided efficient and timely feedback and made me feel that my study always had its place amongst his numerous projects. He provided me and my colleagues with an environment of discussions and exchange from which we all benefited and thrived. I deeply benefited from his mentorship and I am grateful for all what he did to support and guide me during my work.

I would like to thank Dr Mark Lattery for his insightful comments and revealing questions. Our regular discussions played a major role in focusing my work. I would like to also thank Dr Mandana Sobhanzadeh. Her subtle and valuable remarks greatly helped in managing my efforts. My sincere thanks to Dr Pablo Bianucci. His strategic guidance added fluidity to my PhD process.

I thank my fellow graduate students: Franco La Braca, Fereshte Heidary, and Norah Alodiby for the stimulating discussions and assistance. A special thanks to the teachers who administered my study in their classes and to all participating students for their valuable contributions.

I would like to thank my wife, to whom I dedicate this work, and my three kids. Your love and support brought me this far.

TABLE OF CONTENTS

List of figures ix

List of tables x

Introduction xi

Chapter 1: Forces and motion 1

1.1 Purpose of the study 1
1.2 Disturbance in the force 3
1.2.1 Relative findings, briefly 3
1.2.2 Students' alternative views 10
1.3 Teaching in high school 19
1.3.1 An overview of teachers' responsibilities 19
1.3.2 Teaching physics in high school 22
1.4 Educational research and teacher reality 24
1.5 Back to the purpose: bridging the gap 27
1.6 Tackling process and content 31
1.6.1 Process 32
1.6.2 Content 35
1.7 App-like approach 41

Chapter 2: Theory 45

2.1 Reflective Writing 45
2.1.1 Reflective Writing and Hermeneutics 45
2.1.2 An overview of Reflective Writing 49
2.1.3 Understanding with Reflective Writing 53
2.1.4 The course documents 55
2.2 Labatorials 56
2.2.1 About Labatorials 56
2.2.2 How we used Labatorials 70
2.2.3 The fan cart 74
2.3 The force Concept Inventory 76

2.4 Epistemological Beliefs Questionnaire 77
2.5 Presenting the concept map 78

Chapter 3: Methodology 81

3.1 The pilot study 81
3.2 The study - An overview 81
3.3 The study- A justification 83
3.4 Participants 87
3.5 Teacher workshops and follow-up 89
3.6 Presenting the study 97
3.7 The interviews. 98
3.7.1 The interview questions and interviewers 98
3.7.2 The selection of interviewee 99
3.8 Pretests and post-tests 100
3.8.1 The Force Concept Inventory 100
3.8.2 The Discipline-focused Epistemological Beliefs Questionnaire 101
3.8.3 The Concept Map 101

Chapter 4: Results 102

4.1 Combining RW and Labatorials 103
4.1.1 The interviewed students 103
4.1.2 The teachers 108
4.1.3 The FCI results 115
4.1.4 The epistemological test results 121
4.1.5 The concept maps results 124
4.2 The fan cart experiment 136
4.2.1 Interviewed students' analysis of the two-way motion of the fan cart 137
4.2.2 The FCI items 158
4.2.3 Two-way motion of the cart as an introduction to free fall 163

Chapter 5: Conclusion 165

5.1 Contributions of the study 165
5.2 About Labatorials 168
5.3 The fan cart activity: an integrating one 169
5.4 Improving the Concept Map 170

5.5 Advice to the physics teacher 173

5.6 Limitations 175

5.7 The combination works 176

5.8 Where do we go from here? 177

References 179

Appendix A 208

Appendix B 210

Appendix C 219

Appendix D 224

Appendix E 227

LIST OF FIGURES

Figure 1: Free body diagram of a bloc pulled by a rope 38

Figure 2: Hermeneutic circle (El-Helou, 2016) 46

Figure 3: Horizons of the student and of the text (El-Helou, 2016) 47

Figure 4: The fan cart 75

Figure 5: Gain distribution of participants 117

Figure 6: Average gain per course (honors or regular) 118

Figure 7: Gain distribution based on course grade 119

Figure 8: Average gain distribution based on course grade 119

Figure 9: Gain distribution of strong students taking regular courses 120

Figure 10: The Master Map 126

Figure 11: Protocol for the relational scoring method 128

Figure 12: Free body diagrams of student FEV19-R178 140

Figure 13: Force diagrams of student FEU28 150

Figure 14: Force diagrams of students FES28 155

LIST OF TABLES

Table 1: Reflective writing rubric 52

Table 2: Topics covered in the course documents, RWs and Labatorials 82

Table 3: Distribution of 210 participants over school, teacher, language and gender.... 88

Table 4: Participants selected for the interviews 100

Table 5: Average normalized gain per teacher and for all teachers........ 117

Table 6: Items per factor of the DFEBQ 122

Table 7: DFEBQ mean scores per factor on the pretest (Pr) and Post-test (Po)........ 122

Table 8: Paired t-Test for each factor of the DFEBQ 123

Table 9: Description of the concepts related by the propositions of the Master Map .. 128

Table 10: Mean score per rater for the relational with MM method 132

Table 11: Paired t-test results for the relational and MM method 133

Table 12: Mean score per rater for the holistic with MM method........ 134

Table 13: Paired t-test results for the holistic and MM method 135

Table 14: Interviewed students' analysis of the fan cart experiment 138

Table 15: Cross-tabulation of answer choices of item 13 of the FCI 159

Table 16: Cross-tabulation of answer choices of item 18 of the FCI 160

Table 17: Cross-tabulation of answer choices of item 30 of the FCI 161

Table 18: Correlation of items 13, 18, 30 and Normalized Gain (N. Gain) of the FCI 162

Table 19: Post interviews transcript 227

INTRODUCTION

Throughout my career as a teacher and as a researcher, I always felt that I'm standing on the fault line between what research produces and the teaching practices used in the classroom. I had the opportunity to work with top researchers and to witness teaching in top rated high schools. For my PhD research, I did not want to work on anything which could not be directly used by teachers. Having spent over 24 years teaching physics in high school, I wanted my work to be helpful to both physics teachers and their students in overcoming the challenges of this fascinating subject.

What is more challenging in physics than forces and motion? Teaching forces and motion is still an unresolved hurdle in high school (and beyond, in general). Student-centered methods have proven to be effective, but their implementation can be cumbersome. In this work we combined simple tools in a low impact process, which can be used by high school physics teachers with minimum adjustments to their task organization, and without adding to their workload. We aimed at establishing a process through which students are motivated to take charge of their own learning under the supervision and guidance of their teachers.

I managed this research as both a teacher and a researcher. I find myself conveniently located to address the needs of high school physics teachers based on findings presented by research. When the topic is *forces and motion*, almost any study in physics education research is related, in one way or the other, to the work we are doing. One of the biggest challenges I faced in this study was to maintain focus on the main question. Each of the tools used in this study (Labatorials, Reflective Writing, the Force Concept Inventory, course documents, concept maps and the epistemological test) pulls the study in its direction and away from the main goal.

We focused on key ideas that could improve students' understanding of forces and motion. The means of deployment of those ideas are mainly interactive labs called Labatorials which harbor discussions fueled by Reflective Writings. Reflective Writing is a metacognitive activity that incites students to reflect on their learning process. We like to consider our approach as a path wide enough for a few students in teams, where they can walk side by side. The path is challenging yet possible. It twists, changes elevations and leads to an open area, not necessarily to a specific corner of that area. This area is at a certain altitude and it offers a better view of the world. A view where one sees other roads including the path one took to get there. We like to imagine this new area as right above the initial location, and that a helical path led there. Along the way, students in teams assist each other and they acquire, hopefully, skills. The teacher is present along the path, providing encouragement and guidance when needed, and assistance when teams stall.

There is a clash between what research produces and what is happening in schools. Solutions proposed by research are often not applicable in a classroom of 30 students. High school teachers do not have the time, nor the ability, to test and adapt methods proposed by research. This increases the value of our study which attempts to bridge the gap between researchers and teachers. In my situation, I experienced this gap long before I read about it in articles. This gap helped fuel my drive to where I am today, presenting what I hope to be a contribution to improving the teaching and learning of dynamics.

This study was conducted in bilingual Montreal. All the documents were produced and used in both French and English. For simplicity, only English documents are included in this thesis.

Chapter 1: Forces and motion

In this chapter, we present the purpose of the study and we explore relevant ideas and findings which justify the study and the role it can play in improving students' understanding of forces and motion in high school. We will go over the difficulties students have in dealing with forces and motion and the consequent challenges facing teachers in high school and the corresponding educational research.

1.1 Purpose of the study

In the past four decades, research has put forward numerous products (theories, processes and tools) to improve students' knowledge of physics. It should not be surprising that there is no single tool, theory or process that has been proven successful in all situations and all classrooms. The diversity of the educational field across institutions, students, curricula, cultures and countries is too overwhelming for any single product presented by research. In the context of this study, we combined Labatorials and Reflective Writing, which have been proven successful in creating positive change in students' knowledge of physics. We also used concept maps and observation of a fan cart. Our choice, which will be justified throughout the first two chapters, was mainly guided by four criteria:

1) The product will be used with high school students in a school setting.
2) The success of the product revealed by research.
3) The theoretical and functional compatibility between the products.
4) The requirements to use the product.

Our aim is to present teachers with a combination of interventions which are applicable under different restrictions and adaptable to their course needs. We will argue why this study deserves its place and will spend the rest of this chapter and the following chapter justifying our proposals. We will add more clarity to the purpose of the study in Section 1.5, once we've covered key arguments which help better situate the study.

Why this study? The work on this study was driven simultaneously by two goals:

1) It attempts to answers a persistent lingering need for an efficient and applicable process to teach forces and motion in high school. Teaching forces and motion is still accompanied, as it did decades ago, by an array of difficulties. Section 1.2 explores the challenges of teaching forces and motion in high school and beyond.
2) It attempts to bridge what appears to be a fault line between researchers on one side and high school teachers on the other side. Section 1.4 is dedicated to an overview of the gap separating researchers from teachers.

One of the central messages by Hattie (2009), in his much-acclaimed meta-analysis on predictors of student achievement, is that teachers play a central role. Numerous studies have placed critical importance on the impact teachers have on student outcomes (e.g., Hill, Rowan, & Ball, 2005; Kunter et al., 2013; Sadler, Sonnert, Coyle, Cook-Smith, & Miller, 2013). Teachers' practices are not necessarily what researchers recommend. Researchers' findings and recommendations struggle to reach the teachers, or when they do reach them, they are difficult or impractical to deploy in teachers' classrooms. Researchers design, research, analyse results and make recommendations in their publications. Teachers on the other side, are interacting with their students in their classroom or labs, following a curriculum and activities in a manual, giving homework, and preparing and correcting tests.

Our study aims at bridging the gap between what researchers find and how teachers teach. It combines key recommendations made by research about content and process with simple effective interactive engagement methods (Labatorials and RW) which are easy to apply by high school physics teachers. The teaching situations presented in our Labatorials has previously only been covered at the post-secondary level. Additionally, our process brings rigour to the details with which all the interventions found in this thesis are addressed. The added details are based on student difficulties as revealed by research. This combination tools, processes and content intends to practically help physics teachers in their daily routines in covering one of the most difficult (and beautiful) parts of physics.

1.2 Disturbance in the force

Teachers would wish to have students walk in their classroom either not knowing anything about forces and motion or knowing perfectly well all the Newtonian ideas. Then students would spend their time receiving the knowledge from the teachers and become instant experts. If they already know key ideas, students would explore with their teachers the implications that occur in different situations. Unfortunately, decades of research have shown that neither of those two scenarios is remotely close to reality.

1.2.1 Relative findings, briefly

In this section we highlight the main research trends and results which influenced science education research and teaching in general and physics in particular.

1.2.1.1 Coherence or fragmentation

Research has shown that students in science courses, like physics, biology and chemistry, strongly hold understandings of concepts that are very different from the ways scientists understand the same concepts (e.g.,Chu, Treagust, & Chandrasegaran, 2008; Hardy, Jonen, Moller, & Stern, 2006; Özmen, 2004). In addition, research has shown that the views students hold, prior to instruction, often remain unchanged after traditional instruction (e.g.,Champagne, Klopfer, & Anderson, 1980; Gunstone & White, 1981; Hake, 1998; Hestenes, Wells, & Swackhamer, 1992; Spatz, Hopf, Wilhelm, Waltner, & Wiesner, 2020; Whitaker, 1983).

Recognizing the importance of the role played by students' prior ideas in the learning process, numerous articles on this topic were published over the past decades which mainly debated two dominant perspectives. One perspective views students' prior, or acquired, knowledge as coherent or theory-like. (e.g., Driver & Easley, 1978; Ioannides & Vosniadou, 2002; McCloskey, 1983; Posner, Strike, Hewson, & Gertzog, 1982; Vosniadou, 2002; Vosniadou, Vamvakoussi, & Skopeliti, 2008). Under this perspective, students use coherent conceptual structures in their efforts to explain, with consistency, a variety of phenomena. Findings under this perspective revealed significant differences between students' prior ideas and those held by scientists. Several terms were used to identify these alternative ideas which include misconceptions, conceptual frameworks, conceptions or alternative conceptions. Many of these studies concluded that misconceptions are coherent, like theories, and robust. i.e. difficult to change. One prominent theory under this perspective is the theory of conceptual change discussed in Section 1.2.2.1. Another is the framework theory presented in Section 1.2.2.3.

Under the second perspective, students' knowledge is viewed as fragmented or in pieces (e.g., Clark & Jorde, 2004; Clark, 2006; diSessa, 1983; 1988; 2008; 2018; Harrison, Grayson, & Treagust, 1999; Shymansky et al., 1997; Smith, diSessa, & Roschelle, 1993). According to this perspective, "knowledge elements" are activated depending on the situation studied or being analyzed. diSessa (1993) called these "knowledge elements" phenomenological primitives (p-prims) which he presented as elementary pieces of knowledge that can be combined with other such pieces, to formulate an understanding of a particular phenomenon (diSessa, 1988; Taber & García-Franco, 2010). diSessa's p-prims are discussed in Section 1.2.2.2.

How students' views are classified, as coherent or fragmented, may impact the strategies used in the educational process. diSessa, Gillespie, and Esterly (2004) noted that for fragmented views, an "extended collection and organization of elements along the path to expertise" is required. As for coherent views, strategies based on debate and argumentations might be effective. On the strategies deployed in case of coherence or of fragmentation, Lattery (2016) stated:

> What is at stake in this debate? If student knowledge is a hopelessly disorganize jumble of ideas, instruction should build scientific concepts from the most productive and familiar "pieces", an approach taken with the *bridging technique*. However, if this knowledge is more-or-less coherent, instruction should confront student ideas with logical arguments and experimental evidence, a tactic taken by the *elicit and challenge approach* (Emphasis in the original, p. 233)

The bridging technique is presented in Section 2.2.1.2 and the "elicit and challenge" approach is highlighted in Sections 1.2.2.1 and 2.2.1.2.

1.2.1.2 About forces

This section presents an overview of the difficulties students encounter in the physics course and those related to the concept of force in particular. The difficulties uncovered are common to both coherence and fragmentation perspectives and are related to students' initial views about forces and motion. Vosniadou (2002) expressed the differences in how researchers describe students' naïve or initial alternative views:

> Researchers in science education and cognitive science seem to agree that naïve physics exerts a great deal of influence on the way new information is understood and science concepts are acquired, but disagree on how to characterize the exact nature of naïve physics (p. 61).

Compared to other sciences, Physics, namely mechanics, seems to be the area where students have the largest number of difficulties (e.g., Duit & Treagust, 2003; Reiner, Slotta, Chi, & Resnik, 2000; Rowlands, Graham, Berry, & Mcwilliam, 2007; Stewart, Griffin, & Stewart, 2007) When studying mechanics, students in introductory-level physics courses have been found to have significant misconceptions about important topics such as work, motion, and force (e.g., Savinainen, Scott, & Viiri, 2005; Slotta & Chi, 2006). Although preconceived notions can differ slightly from student to student, research has shown that there are many common elements among the vast majority of learners (e.g.,Driver, Rushworth, Squires, & Wood-Robinson, 2005; Duit & Treagust, 2012)

Arons and Miner (1990) argued that the concept of force, along with inertia, have historically been two of the most difficult challenges for students. In a study by Sadanand and Kess (1990), 82% of senior high-school students referred to the idea that a force is necessary to maintain motion. Hestenes et al. (1992) stated: "The central concept of Newtonian mechanics is force…Without this concept, the rest of mechanics is useless, if not meaningless."

Early discussion about students' conceptions of force viewed those as similar to the ones held in medieval times (Driver & Easley, 1978; Hewson & Hewson, 1984; McCloskey, 1983; Posner et al., 1982). McCloskey (1983), for example, compared students' ideas of force to those identified by the impetus theory which posited “impetus” as the causal agent of motion, “injected” into a moving object and then fading or draining away. Hestenes et al. (1992) identified impetus as: “conceived to be an inanimate "motive power" or "intrinsic force" that *keeps things moving”*. That evidence that a student believes “in some kind of impetus” is therefore evidence that the First Law is not understood. Impetus theorists differed over whether impetus would simply fade away on its own or be drained away by impediments to the object’s motion (Brown & Hammer, 2009).

Lattery (2016) offers a detailed description of decay models of force including the long decay model and the truncated model. He also presented an overview of related research and findings. Research promoting coherence describes the decay model using an alternative interpretation of the motion of a body tossed vertically upward. The decay model is arguably related to force as impetus because its interpretation recalls the impetus view of force as being a property of the object instead of that of an interaction. Under the coherence view, the force exerted by the hand on the body, tossing it upward, is greater than the force of gravity pulling the body downward and therefore the body moves upward. Even when the hand is no longer in contact with the body, the force of the hand remains in the body during its upward motion only its value is decreasing. Now, the body reaches the peak, the force of the hand has decreased enough to reach the same value as the gravitational pull, which prevents the body from continuing its upward motion. Under the long decay model, the force of the hand keeps “decaying”, and because it has reached a value less than that of the weight the body is brought down by the weight. During the downward motion of the body, the force of the hand keeps on decaying. At the peak, those who adopt the long decay model consider that the body stopped moving because the resultant force is null. As described by Lattery (2016), the truncated decay model is similar to the long decay model in the phase before the peak. Beyond that point, in the truncated decay model, the force of the hand is completely eliminated which would result in a Newtonian interpretation for the remainder of the motion of the body. Lattery (2016) also elaborated on an alternative interpretation of the vertical toss using the fragmentation perspective. In this interpretation, the imputes model, which is recognized under the coherence approach, is replaced by the “overcoming”, “dying away” and “balancing” p-prims (discussed in Section 1.2.2.2) defined by diSessa (1983).

What makes the long decay model interesting is because it manifests two main difficulties related to forces and motion which are: the “force inside the body” and that “motion means force” (Lattery, 2016). The “force inside the body” is seen when the force of the hand persists on the body even when the hand is no longer in contact with the body. This difficulty finds an interpretation in the “impetus” under the “coherence” perspective, and in the “dying away”, under the fragmentation perspective. The “motion means force” is seen during the upward motion of the body, which requires the presence of an upward force to justify the upward motion of the body. Similarly, this difficulty is interpreted using the “impetus” or using the “overcoming” p-prim. The decay model is important in this study because of one central experiment in the last Labatorial, which is the two-way trip of the fan cart, discussed in Sections 2.2.3 and 4.2.

Numerous articles have been published which reviewed existing literature about recurrent difficulties students have when it comes to the concept of force (e.g.,Bao, Hogg, & Zollman, 2002; Kariotoglou, Spyrtou, & Tselfes, 2009; Montanero, Suero, Perez, & Pardo, 2002). The findings commonly indicate that after teaching, most students still have a limited understanding of the force concept. As we have shown in the previous paragraph, these difficulties are not bound to either coherence, fragmentation or any other perspective. The most common difficulties revealed are:

- A force is an innate or acquired property of objects. Force is seen as a single-body property rather than the outcome of the interaction of two bodies.
- Students have problems identifying the forces acting during an interaction.
- Students tend to apply both action and reaction to the same body and, in some cases—for instance when a body is in motion—they find it difficult to accept the equal magnitude of forces: "action always overcomes reaction when two bodies move together"
- A reaction is not recognized in the case of a stationary body (a car, or a table) or that there is no reason to consider the balance of forces or that its cause is not identified. For example, they think that the upward force of a table on a book is a form of resistance, or that it comes from air pressure, air molecules, compression, and so on.
- That motion implies force. That motion in a certain direction must entail a combined fore in the same direction.
- A constant force induces constant motion
- Faster objects exert a larger force.
- Bigger objects exert a larger force.
- Objects that do the pushing, exert a larger force.
- Objects that are speeding up (accelerating), exert a larger force

These and other findings indicate that students' understanding of the force concept is very often context-dependent; a student may show correct understanding in some exercises involving the force concept but fail to apply this knowledge in other situations (Palmer, 1997;

Steinberg & Sabella, 1997). There is proof that students' understanding of the concept of force is representation dependent (Meltzer, 2005; Nieminen, Savinainen, & Viiri, 2012). For example, students may be able to recognize a correct answer, in a verbal representation, when found in a multiple-choice format but not, for instance, in a vectorial or bar chart representation. Hubber, Tytler, and Haslam (2010) argued that conceptual difficulties with the concept of force are fundamentally representational in nature since learning about forces involves the active generation and coordinating of relevant representations.

1.2.2 Students' alternative views

In this section, we explore the student's alternative views about forces and motion. These are views that students develop or acquire, before or during instruction, that are different from scientific views, in our case, Newtonian views.

1.2.2.1 Misconceptions

The idea that students enter the physics course with misconceptions about force and motion can be found in the works of science educators like Novak (1977) and Driver and Easley (1978). Halloun (2007, p. 171) defines misconceptions as "a naïve conception that is entirely at odds with its scientific counterpart, and that is futile in all practical respects".

The work of Posner et al. (1982) guided the research and practice on conceptual change in science education for many years. They argue that learning and inquiry occur against a background of the learner's current concepts. When a new phenomenon is encountered, the learner's investigation of this phenomenon is based on his/her current concepts. They identify two patterns of conceptual change in learning: assimilation and accommodation. Assimilation occurs when the student uses current concepts to deal with the phenomenon. If those concepts do not allow him/her to grasp the new phenomenon successfully, then the student must either replace or reorganize these concepts. This accommodation of current concepts is what they identify as conceptual change. They highlight what is known as the elicit-and-challenge strategy founded on the idea that conceptual change is triggered by a dissatisfaction with the current concepts. Brown and Hammer (2009, p. 130) described the stages of conceptual change:

> First, there needs to be dissatisfaction with the existing theory. Just as scientists would not be convinced of a new theoretical framework without compelling evidence that their existing theory is inadequate, students need to experience problems with prior conceptions in order for them to change. Then the new theory needs to be seen as intelligible (able to be understood), plausible (believable as a potentially true theory), and fruitful (opening up new avenues of thought or investigation not possible with the old theory).

The process of replacing concepts, triggered by cognitive conflict, with more suitable ones, over a short period of time, became subject to criticism (Chi, Slotta, & De Leeuw, 1994; diSessa, 1983; Pintrich, Marx, & Boyle, 1993; Vosniadou, 1994). Caravita and Halden (1994) argued that conceptual change happens in larger educational, situational, and socio-cultural contexts, that it is influenced by affective and motivational factors and that it takes time to be accomplished. The original theory of misconceptions promotes that students implicitly adopt the same principles followed by impetus theorists. However, in reviewing related research, Brown and Hammer (2009) cite several studies showing that students' views are "not typically systematic".

Dealing with students' misconceptions through conceptual change was the driving force for science education research for decades that followed. In their review of conceptual change in the past years, Duit and Treagust (2003) explored the development of conceptual change in research and learning and how it has given rise to a multi-perspective view of science learning and instruction. Their review shows that conceptual change approaches, developed in the 80s and early 90s, contributed substantially to improving science learning and teaching. However, they outline limitations and one-sidedness approaches which were highlighted by Vosniadou's (1994) framework theory and mental model perspective (discussed in section 1.2.2.3), Chi et al. (1994) ontological category perspective and Pintrich et al. (1993) motivational perspective. In addition, we explore diSessa's view of students' knowledge as being in pieces (discussed in Section 1.2.2.2).

Pintrich et al. (1993) present an extensive review of the literature highlighting the importance of motivation in conceptual change. That considering ways in which students' motivational beliefs about themselves as learners and the roles of individuals in a classroom learning community can facilitate or hinder conceptual change. The actual classroom context and the types of activities play a decisive role in students' motivation and involvement.

Chi et al. (1994) define conceptual change as a shift from one ontological category to another. They define three ontological categories (called trees) which are Matter (or Things), Process and Mental State. An entity belongs to one of the three categories. For example, a wire, a ball, a battery and Earth are Matter-based (or things), a wave, an electrical current, a force or gravity are processes; a dream or an idea are mental states. Each category or tree includes subcategories. What they consider as a situation that necessitates conceptual change is when for a student an entity is not in the correct category. For example, if a student considers an electrical current as Matter instead of a Process, then changing the ontological category from Matter to process counts as a conceptual change and it is not easy to achieve. Whereas changing an entity from one subcategory to another subcategory of the same tree does not count as a conceptual change and is normally easier to achieve. For example, it is common that children classify a plant as non-living matter because of its lack of mobility. It is however easy to convince them that a plant counts as living matter by looking at its other attributes like growing and dying. instead of non-living.

Chi et al. (1994) also found that novices are predisposed to classify physics concepts as matter-based, namely the concept of force. Students tend to consider the force as in the body (Impetus) and gravity as being in Earth. What follows is that any new instruction about the force will also be attributed to matter instead of process. A complete understanding of the concept of force cannot be achieved unless, the students undergo a conceptual change to relocate the force to its true ontological category. In addition, the concept of force belongs to the subcategory of processes known as Constraint-Based. This subcategory is difficult to define, let alone teach and understand, which adds to the challenges of teaching the concept of force to students. The Constraint-Based subcategory can be confusing to learners; its concepts are related to matter-based entities without being matter-based. For example, an electric current is related to the battery and the wire, which are matter, but not the current. Similarly, the force describes an interaction between two matter-based bodies, but the force is not matter based. They argue that the ontological perspective which underlines conceptual change serves a valuable teaching function where teachers can highlight the ontological differences; thus, facilitating conceptual change.

In a review of the research, Limón (2001) identified 3 approaches to promote conceptual change in the classroom: a) through the production of cognitive conflict using anomalous data; b) using analogies to guide students' change; and c) cooperative and shared learning to promote collective discussion of ideas. She also reported difficulties in implementing conceptual change that could explain its limited success. Some of the difficulties are related to motivational and social factors, others are related to practical problems pertaining to the implementation of the cognitive conflict strategy in real school settings.

1.2.2.2 Knowledge in pieces

diSessa (1983) introduced the idea of Knowledge in Pieces (KiP) to account for students' views about physics. He argued that students' knowledge is formed of an unstructured collection of simple elements that he calls "phenomenological primitives" or "p-prims". These p-prims are mental resources created from students' direct experiences of the physical world. They are primitive notions used by students to interpret an observed phenomenon and could be considered as the building block of more complex mental structures. P-prims in physics occupy a similar level to that of axioms in math "which similarly stand without significant explanatory structure or justification" (diSessa, 1983, p. 15). P-prims are assumed to be organized in a conceptual network and seem to be activated through a mechanism of recognition, which depends on the connections that p-prims have to the other elements of the knowledge system (diSessa, 1993). An example of a p-prim given by diSessa (1983) is the "dying away", a recurring tendency in everyday life. It is seen in the fading oscillation of a pendulum, or the fading sound of a bell. Another example of a p-prim is the "force as a mover", the tendency of a body to move in the direction of the force pushing it. "Balancing" and "unbalancing" are p-prims related to an effect resulting from the presence of two opposing agents. If the two agents are equal, then there is no effect resulting from their presence. If they are not equal, then an effect is present. In an example given by diSessa (1996) the interviewed student "J" uses a combination of p-prims to describe the motion of a body tossed vertically upward. "J" uses the "unbalancing" between the force of the hand and the weight of the body to justify why the body moves upward. She then justifies the upward motion to the top by using a combination of the “force as a mover” and the “dying away”. In her justification, the force of the hand is larger than the weight hence the slowing down of the body. At the top, she uses the “balancing” between the force of the hand and the weight to justify that the body stops the top. At this point, the force of the hand has decreased enough to balance the weight.

diSessa (1993) considers the process of learning science as combining and systematizing the pieces of knowledge into more complex structures to interpret natural phenomena. During this process, the function of p-prims changes from isolated, self-explanatory resources to become elements of a relatively complex knowledge structures like physics laws. For the expert learner, p-prims "can no longer be self-explanatory, but just refer to much more complex knowledge structures, physics laws, etc. for justification" (diSessa, 1993, p. 114).

Unlike misconceptions, in diSessa’s view, p-prims are not unwanted distorted ideas that should be replaced, they are rather basic elements of thought patterns that can be exploited to build more complex mental structures bringing the student closer to the expert view. Smith et al. (1993) criticized the misconceptions position because it focuses on the mistakes in students’ prior knowledge without considering their productive ideas that can be used to build a more sophisticated understanding of math and science.

1.2.2.3 Framework theories

Vosniadou (1994), presents an alternative view to students’ knowledge of science in what is known as the framework theory. She situates the framework theory apart from misconceptions and KiP (Vosniadou, 2002, p. 61):

> …children start the knowledge acquisition process by organizing the multiplicity of their sensory experiences under the influence of everyday culture and language into narrow but coherent explanatory frameworks that are different from the currently accepted science. Naive physics thus does not consist of a collection of unstructured knowledge elements or of stable misconceptions but constitutes a complex system that includes perceptual information, beliefs, presuppositions, and mental representations. This knowledge system represents children's attempts to organize their perceptual experiences and information they receive from the culture into coherent explanatory frameworks.

The framework theory is viewed as consisting of basic "presuppositions" about how physical bodies function in the world. For example, the presupposition that "physical objects are solid", that "space is organized in terms of the directions of up/down", that "unsupported objects fall down", that "rest is the natural state of physical objects" and "motion needs to be explained" and that "abstract entities such as force, heat, weight, etc. are properties of objects" (Ioannides & Vosniadou, 2002). Brown and Hammer (2009) viewed the framework theory as a kind of a "nucleus" around which "observations and other knowledge are organized into models in specific situations".

Under the framework theory, misconceptions are not viewed as independent faulty conceptions, but as elements of a knowledge system comprised of different parts and organized in complex ways. That conceptual change is a gradual theory of change that takes a lot of time as opposed to a sudden restructuring of knowledge. It distinguishes between the learner's initial framework theory of physics (a naïve physics), prior to systematic instruction, and misconceptions that occur after instruction. Vosniadou, Ioannides, Dimitrakopoulou, and Papademetriou (2001) argued that misconception (what they call synthetic models) form as a result of the interference between new information presented to the students and prior knowledge. That knowledge acquisition is a gradual process during which existing knowledge structures are slowly revised. Framework theory focuses primarily on cognitive aspects of conceptual change; however, it is considered complementary and not contradictory to approaches which deal with metaconceptual, motivational, affective and socio/cultural factors (Vosniadou, 2001; Vosniadou, Vamvakoussi, & Skopeliti, 2008).

As a tool and process for instruction to promote conceptual change, this theory encourages the use of analogies and models allowing mappings across domains, thought experiments and limited case analyses. It also emphasizes social kinds of mechanisms that can facilitate conceptual change, like collaboration and class discussion (Vosniadou, 2008).

Brown and Hammer (2009, p. 133) noted subtle differences between diSessa's Knowledge in Pieces and Vosniadou's framework theory:

> Where Vosniadou posits framework presuppositions that act as "constraints" on reasoning and intuitive modeling, diSessa posits elements that are more central in the knowledge system, and so may be cued with high priority in a wide variety of circumstances. For Vosniadou, presuppositions that differ from expert reasoning must be revised; in this sense, they are structural misconceptions, albeit at an implicit rather than conscious level. For diSessa, development to expertise may require the addition of new primitives, but existing primitives change only in activation priorities, not in their semantics.

1.2.2.4 Complex systems theory

In their attempt to integrate what seems to be conflicting views of conceptual change, Brown and Hammer (2009) proposed the complex systems theory. It's not intended as a new original approach, but as a perspective which "the field has been moving toward". The complex systems theory deals with the interaction between the components of a dynamical system where what happens to one component affects another, and in return, affects back the first component. This produces a non-linear system where a small change in one part of the system may lead to disproportionate effects on all components. A double pendulum is an example of a complex system.

The theory of complex systems gained traction in educational psychology and in modeling cognition (Bogartz, 1994; Jacobson & Wilensky, 2006; Van Geert, 1998). When applied to cognition, the complex systems theory considers students' conceptual thought as a dynamic system. A central idea of a complex system is that a robust stable state may emerge from what appears to be unguided random interaction between the components of a system.

The components of the dynamic system can be misconceptions, p-prims as described by diSessa, or presuppositions as described by Vosniadou. This consideration may account for the stabilities in the students' thought patterns, brought forward by the theory of conceptual change, which are difficult to change. It also conforms to the perspectives of diSessa and Vosniadou. In each of their approaches to students' views, both diSessa and Vosniadou argue that students form more complex structures out of more basic elements. The basic element for diSessa are p-prims and for Vosniadou the basic elements are presuppositions.

According to Brown and Hammer (2009), the complex systems theory may explain the formation of long-lasting thought patterns from the interactions between the components as well as the morphing of those patterns into other patterns. It can also account for motivational, situational, and socio-cultural factors known to impact conceptual change. They see complex systems theory as enabling synthesis of previous research findings.

1.3 Teaching in high school

In this section, we explore the tasks related to teaching in high school. Most research examines the difficulties and responsibilities facing novice teachers. It should be noted that experienced teachers have arguably similar difficulties and responsibilities. The difference between novice teachers and experienced teachers is that the latter's experience helps in coping with the load, but that load is not reduced.

1.3.1 An overview of teachers' responsibilities

Smithers and Robinson (2003) conducted a study on over 5000 teachers from the UK who left the profession. They found that the five main factors that influence teachers' decisions to leave were: workload, new challenges, the school situation, salary and personal circumstances. The workload was by far the most important, and salary the least. Other studies mainly from the USA, UK and Australia also placed the lack of job satisfaction, due to teachers' heavy workload and other pressures, as the most important reason for leaving the profession (De Nobile & McCormick, 2008; DeAngelis & Presley, 2011; Hobson et al., 2007; Ladd, 2007).

Among the main duties associated with instruction, planning is considered to occupy the central role (Forzani, 2014; Windschitl, Thompson, Braaten, & Stroupe, 2012). Clark and Yinger (1979) listed eight reasons for why teachers plan: determine a direction to take a lesson; build confidence and security about the lesson; learn the material or refresh their memory by studying and reviewing the content; organize the material for presentation; make decisions on timing and flow of the lesson; organize students; provide an outline for instruction and evaluation; meet organizational needs such as daily, weekly, and semester schedules. The teacher is expected to develop course plans from a knowledge of the subject; local curriculum and assessment regulations; student ability/achievement levels in the classes taught; student and societal needs; and available resources (Scriven, 1994). Research indicates that planning is one of the ways teachers demonstrate effective teaching behaviors (Byra & Coulon, 1994; Clark & Yinger, 1979; Griffey & Housner, 1991; Housner & Griffey, 1985). When considered over a school year, teachers' planning routine could include as many as eight different types of plans including long-range, short-range, yearly, term, unit, weekly, daily, and lesson (Yinger, 1980).

Scriven (1994) details the different tasks associated with teaching, some of which are mentioned, and many are not mentioned by employers nor by teacher preparation programs:

> teachers always have other duties in a school, ranging from committee work and attendance at meetings where policy changes are explained or discussed, to taking attendance, developing and reacting to curriculum changes, supervision of playgrounds or study halls, service at school events or on community-school committees, counseling of various types, and out-of-class activities—the extent to which the teacher expected to do syllabus design and materials selection, to contact parents, to run school projects, clubs and societies, to doing special student reviews, to organizing trips and supervising or coaching sports and other recreational activities. These duties vary greatly from school to school, sometimes between different management regimes in the one school at

> different times, and as between staff of differing seniority. Skill in performing some of these duties may be very important and by no means trivial or untrainable; for example, skill in enlisting support from parents in the enterprise of motivating and assisting their children. Since a school often cannot run or cannot run well without teachers performing some of these duties including some that are not of direct educational significance, they should not be regarded as minor, dispensable, or an imposition on teachers; they are and always have been part of the job in all schools, perhaps even more so in private schools (Scriven, 1994, p. 29)

Many of the duties, especially those not directly related to instruction, have been marginalized in teacher training programs to emphasize teaching practices aimed at delivering content (Forzani, 2014; Kennedy, 2016). Carlone (2003) noted that the implementation of new teaching approaches is hindered by the school science culture and the expectations of students, parents, and teachers.

It is well documented that the first years of teaching are difficult for any teacher (Darling-Hammond, 1990; Wilson, 2011). Beginning teachers may experience some anxiety, emotional distress, and a lack of self-care (Chang, 2009; Fimian & Blanton, 1987; Kyriacou, 2011). DiCicco, Jordan, and Sabella (2019) conducted a study with novice STEM teachers to evaluate their expectations of non-instructional tasks. Their interviews with participating teachers revealed that the duties of teaching extended beyond the standard school hours and encroached on their personal time in addition to all the resources they must manage and all the legal aspects of the professions.

The purpose of this overview is to give an idea of the array of tasks involved in teaching in high school and of what is expected from high school teachers. Many of the points mentioned deserve more scrutiny as well as other teaching circumstances and institutional constraints such as: the number of students per group; the influence of parents; the maturity of students; classroom management; students' motivation; coordinating between many teachers teaching the same level, standardized exams, teaching periods lost because of numerous activities…. However, such scrutiny, as important as it may be, diverges from the goals of this study.

1.3.2 Teaching physics in high school

The circumstances highlighted in the previous sections apply to all teachers and, in particular, the physics teacher. In this section we mention additional challenges to teaching physics in high school. When it comes to physics, research has shown that secondary school students view this subject as difficult and demanding (Angell, Guttersrud, Henriksen, & Isnes, 2004; Kessels, Rau, & Hannover, 2006). Students show lack of interest in the subject and in pursuing careers related to physics (Barmby, Kind, & Jones, 2008; Jenkins & Nelson, 2005; Kessels et al., 2006; Osborne, Simon, & Collins, 2003).

In addition to managing an unpopular subject, Physics teachers must also manage students' difficulties in math. Lack of mathematical skills is viewed as a hurdle to physics understanding (Orton & Roper, 2000), or the transition from physical situations to mathematical representations is considered as the real challenge (De Lozano & Cardenas, 2002). In their review of the literature, Duit and Treagust (2003) suggest that some Physics teachers hold limited views on the aims of physics instruction, and that they are not familiar with the kinds of pre-instructional views that students may have. They also suggested that many experienced teachers have difficulty creating inquiry-based classroom environments. Novice teachers may be incapable or unwilling to enact teaching science as inquiry in their actual classrooms (McGinnis, Parker, & Graeber, 2004; Newman et al., 2004). Kariotoglou et al. (2009) showed in their study (N=264), that a significant number of pre-service teachers experience difficulty in identifying the interactions in different contexts, and even in different cases within the same context. They also found they misrepresent the arrow representing the force by placing it on the body exerting the force and that they hold the alternative view that the larger the body exerting the force the larger the force is. Savinainen, Mäkynen, Nieminen, and Viiri (2017) argued that some Physics teachers may not even realize how challenging it is for students to learn the concept of force and Newton's third law.

Weaver (1998) argued that educational strategies might fail when teachers have limited class periods to implement it or are pressed to cover the program in time. Weaver (1998) also reported that teachers often lack first-hand experience of real scientific inquiry which reduces their abilities to manage its demands. Moreover, teachers are uncomfortable promoting discussions when they doubt their mastery of the subject. When novice teachers start their careers, they find it daunting to initiate inquiry-based learning when their colleagues hold negative views toward inquiry (Crawford, 2007; Roth, McGinn, & Bowen, 1998). Crawford (2007) reviewed research which shows that even experienced teachers have difficulty in creating classroom environments based on inquiry.

In the province of Quebec, for example, although high school teachers must undergo teacher training to be licensed to teach in the province, that training does not necessarily need to be in Physics teaching to be a licensed physics teacher (MEESR, 2015). This decision is left to the administrators who base it on an evaluation of the background and academic training of licensed teachers. Since physics teachers, who are trained in physics and teaching physics, encounter subject-related difficulties, one wonders how teachers, who did not undergo such training, can cope with the challenges of their tasks.

1.4 Educational research and teacher reality

The gap between educational research and practices adopted in educational institutions has been the topic of numerous articles over the past decades. Both researchers and practitioners recognise the existence of a gap between educational research and practice (Burkhardt & Schoenfeld, 2003; Gore & Gitlin, 2004; Hargreaves, 2007; Kennedy, 1997; Levin, 2004; Levin & O'Donnell, 1999). There are numerous articles which indicate that educators have made little use of research (Burkhardt & Schoenfeld, 2003; McIntyre, 2005). Educational researchers express frustration that their research results are seldom used in practice (Pieters & de Vries, 2007). It is argued that: a) problems tackled by educational researchers lack practical meaning because they are typically different from those experienced by teachers in their daily work (Broekkamp & van Hout-Wolters, 2007; Burkhardt & Schoenfeld, 2003; Kennedy, 1997); b) teachers and researchers have different interests and goals. That while researchers aim for generalizable and abstract propositions, teachers search for concrete and practical recommendations which could help them in their classroom practice (McIntyre, 2005); c) Practitioners (teachers, policy makers, publishers…) believe that educational research is not conclusive or practical. Teachers considered research to be inaccessible, irrelevant, and unreliable. That advice from researchers should be ignored, because researchers do not know what truly transpires in a classroom (Gore & Gitlin, 2004); d) Teachers rarely use research to inform their practice because either academic journals are inaccessible to non-academic audiences (Hemsley-Brown & Sharp, 2003); teachers lack the time to read research and make sense of it (Burkhardt & Schoenfeld, 2003); or teachers struggle in translating research findings into useful actions in their classroom (Broekkamp & van Hout-Wolters, 2007). In a recent study, Neal, Mills, McAlindon, Neal, and Lawlor (2019) maintained that the gap is attributed to the lack of appreciation from the researchers of the various needs of educators. McKenney and Schunn (2018) noted that an important consideration related to the research–practice gap pertains to how (research-generated) knowledge is shared.

The researcher-teacher gap also exists for physics. Duit and Treagust (2003, p. 683) states:

> the gap between what is necessary from the researcher perspective and what may be set into practice by “normal” teachers has increased more and more also. In other words, there is the paradox that in order to adequately address teaching and learning processes, research alienates the teachers and hence widens the “theory-practice” gap. The views of teaching and learning developed in our field are far from normal classroom teachers’ ways of thinking about instruction. The instructional strategies developed by us are far from the routines of normal classes.

In attempting to resolve the knowledge sharing issue, educational researchers have begun promoting modes of inquiry that feature co-creation and organic diffusion of knowledge (McKenney & Reeves, 2018; Penuel, Fishman, Haugan Cheng, & Sabelli, 2011; Sargent, 2015; Stosich, Bocala, & Forman, 2018; Zeichner, Payne, & Brayko, 2015). These modes aim at deriving new knowledge and at building collaboration between researchers and educational practitioners through the iterations of developing solutions to real-world problems. While these approaches are valuable and often effective, their distribution is limited because a research team can work directly with a limited number of educators and they rarely last beyond single projects (McKenney & Schunn, 2018).

Another recognized method for bridging the gap between researchers and practitioners, which is of particular importance to our study, is known as research, development and diffusion (RDD) (Blakely et al., 1987; Dearing et al., 2015; Posner, 2004).). RDD is generally characterized "as being rationalistic, sequential and comprehensive" (Roblin & McKenney, 2019, p. 21). RDD is based on the notion that intermediaries translate the knowledge produced by researchers into usable products made available for practitioners. RDD assigns a central role to mediators and describes the process through which research findings are made accessible to practitioners. Mediators select, combine, and adapt research results which are them diffused to practitioners.

Roblin and McKenney (2019) present the three distinct phases of the RDD model. The first phase (research) aims at advancing knowledge in the field. The development phase aims at utilizing knowledge obtained through research into the design of a solution for an actual problem. This phase also includes systematic testing and evaluation of the developed solution to assess its quality, utility, value and feasibility in natural settings. Diffusion aims at facilitating dissemination and adoption. This phase includes activities aimed at creating awareness, demonstrating effectiveness and utility, and providing training and support.

The RDD model has long been criticized for being unidirectional when it comes to the flow of knowledge. That knowledge flows from researchers to teachers, and that teachers play the role of consumers of knowledge produced by researchers (Biesta, 2007; Posner, 2004). In a recent study, Roblin and McKenney (2019) found that recent educational RDD project regularly incite active involvement of teachers in the development and implementation of educational methods.

Our study uses the RDD model to present tools to high school teachers to teach forces and motion. The designers of the study play the role of the intermediaries who have combined tools and results produced by research in a process presented to teachers to help them in their teaching task. It is pertinent to admit at this point that we used the RDD in a unidirectional manner. Meaning, that we have placed teachers on the receiving end and not on the development of knowledge path. Our position is justified in the following section (Section 1.5) which brings back the discussion to the purpose of the study.

1.5 Back to the purpose: bridging the gap

In the sections of this chapter leading up to this one, we reviewed the different circumstances of teaching physics which justify the purpose and the importance of this study. Here we combine the different arguments to conveniently situate the study.

In Section 1.2 we highlighted the importance of the concept of force and the main difficulties encountered by students related to its understanding. We also explored the misconceptions pertaining to the relationship between force and motion. We reported research results depicting that there is still a need to improve how this essential part of physics is tackled in classrooms. We presented how researchers categorize students' epistemologies about forces and motion as well as their alternative views. We have shown that there is a consensus that efficient classroom practices are related to teachers addressing students' prior knowledge and epistemologies about forces and motion.

We dedicated Section 1.3 to describe the high school teachers' everyday reality and the tasks they have to complete. We have shown that abundant research emphasizes the significant workload associated with teaching in high school. Beyond the workload related to the subject taught, like preparing lesson plans and correcting exams, numerous responsibilities, which come with the job, fall upon the shoulders of teachers. Teachers are left with hardly any time to manage additional tasks. We paid special attention to the difficulties of teaching physics in high school which comes with its own set of challenges. These challenges are either related to the subject, teacher preparation or institutional constraints.

The well-established gap between researchers and teachers was overviewed in Section 1.4. Decades of studies point to the limited ability of researchers to bring teachers to use their results in their practices. Indeed, teachers and researchers having different goals, is one of the causes of this gap. Another cause was that teachers lack the time to combine and integrate research findings into their practices, or they struggle to translate these findings into practical everyday actions in their classrooms.

Research has provided fragmented bits that teachers can use. Only these bits might not be accessible to all teachers, and might not even be compatible with other bits. In many cases researchers do not agree about what is the best course of action; the teachers, on their side of the gap, are going about their business of teaching generations, aware or not of what is happening in academia. They seldom feel the need to abide by what the research has produced. One can even argue that they could be overwhelmed by what research is proposing.

Research is often focused on evaluating a specific problem and on making recommendations on what to emphasize and avoid. These recommendations are usually targeting a specific part of the material. As valuable as they may be, when teachers view results and recommendations from multiple studies, these recommendations may appear fragmented. It is often left to the teacher to synthesis the bits of information and recommendations into a coherent whole. A task which is difficult to undertake considering the burden high school teachers carry. We believe that it is the teachers' responsibility to stay informed, to the best of their abilities, with what research has to offer their field. We also agree with the argument (elaborated in Section 1.4) that research's attempts to adapt their findings to high school reality is lacking. What is lacking is a road map that takes teachers from where they are to where researchers recommend them to be. Researchers did not offer a road map, they offer destinations. In their studies, they conclude on the whereabouts of teachers and their students; researchers point the direction in which the teachers should head to get to the destination. Unfortunately, research rarely offers clear instructions on how to get to the destination. When they do offer instructions, they often apply to specific circumstances that diverge from those in a high school classroom. Our study synthesises and sequences key results produced by research and makes them available for direct use by teachers.

Our study is justified by a) the persisting difficulties in teaching forces in high school; b) the gap hindering research results from reaching teachers in a practical usable way; c) the workload and the conviction of teachers preventing them from dedicating time and effort to advance their teaching practices in accordance with what research suggests. Our study attempts to fill this void by a) benefiting from research products (Labatorials and RW) and results (students' difficulties and epistemologies related to forces and motion); b) combining those in a process adapted for high school physics classroom. Thus, bringing essential usable elements from research and presenting them in a practical way for teachers. This process is akin to what is known as RDD (Research, Development and Diffusion; discussed in Section 1.4). One added advantage to our study is that it presents teachers with a coherent set of ideas and steps to tackle the concept of force and Newton's laws of motion as opposed to the fragmented approach across several studies.

Not all research and findings are intended for classroom use. Roblin and McKenney (2019) argued that research may not be directly concerned with problems of education practice, however, its results serve to inspire development activities. The paradigms of Kuhn (1970), which can be of little use to the average teacher in their daily tasks, constituted foundations for countless research and curriculum development for decades. The seminal work of Chi and her collaborators (Chi et al., 1994; Chi, 2013; Slotta & Chi, 2006) places physical entities in ontological categories based on which they offer a definition of conceptual change. Such a definition can be used by teachers in the preparations of their courses, or in better formulating their arguments with their students. On their own, such notions account for an important, albeit small, portion of what is expected from teachers. Other portions come to play to make a whole for the teacher to work with. Unfortunately, not all the parts produced by research are coherent and, in many cases, explored in Section 1.2, are almost conflicting with one another.

How will the ontological view of Chi et al. (1994), as brilliant and as refined as it may be, affect students' grades on an admission test or on standardized tests when all the questions on those tests require number crunching and mechanical solving techniques? Can the teacher who focuses on preparing their students for such exams be blamed for not tackling students' conceptions from an ontological point of view? Should teachers even be blamed for not showing any concerns with the topic? The point we are trying to make is that, as important as research is, its applicability is equally important. It is inconceivable, especially in schools, to ask teachers not to teach traditional questions and problem-solving strategies and crunching numbers when those are required at higher levels and in entrance exams. Teachers need to dedicate time to such questions, or they will be labeled, by students, their parents and maybe the administration of their schools as “not properly” preparing their students for what is coming.

Hence the need for an initiative like our study which attempts a combination of serval tools and conclusions from research yet adapted to teachers’ needs. Proof that students do not grasp the concept of force and how it relates to motion is well established. What is needed are practical ways to overcome these problems. Our study is an action in this direction. When all listed factors are considered, we believe that our study offers a roadmap for teachers, grounded in research, and covers the fundamentals of dynamics which are the concept of force and Newton’s laws of motion.

In the following section (Section 1.6) we present details on the process and content of our study. Section 1.7 adds more clarity to our approach and situates it as a teaching unit. In Chapter 2: we present details about the educational tools and evaluation tools we used.

1.6 Tackling process and content

In this section, we answer the question: what are physics teachers supposed to do in their classrooms? What we are proposing is a process that uses a sequence of Labatorials and RW. The content within the process is focused on key ideas, revealed by research, aimed at providing students with mental techniques to help them manage the different situations in dynamics. It is inconceivable that teachers can cover all situations in their courses. Hence the focus on the ideas that matter most.

Teaching dynamics involves an array of aspects of how forces relate to motion. It is not only about managing students’ alternative views or difficulties like force as Impetus, motion means force or the decay models. However, those views or difficulties are what cause most problems in analysing situations. In sports, athletes practice a full-body training, yet focus on specific muscles and movements most useful for their sport. When driving a car, every aspect of the process is important for safety, however, the blind spots are the most troubling and they require special attention to understand them and practice their integration to make them a part of good driving habits.

Here we offer a description of the process used and the content. Both process and content are designed to be practically useable in a regular physics classroom in high school

1.6.1 Process

What we mean by process is a combination of structure and steps used to deploy key activities, situations and ideas. The process is centered around two ideas: Cycles (repetitive varied exposures) and discussions. Labatorials and RW tasks are considered as vehicles used to harbor ideas and situations through which the process can be put into action. The main guideline is offering opportunities, repetitively with variations, for students to discuss their ideas of important elements in mechanics with their peers and teachers.

1.6.1.1 Cycles - repetitive varied exposure

The content and sequence of Labatorials and RW are designed to cycle students through situations offering different perspectives of essential elements. Vosniadou (2002) and Lattery (2016) argue that overcoming students' difficulties requires time and different iterations. Savinainen et al. (2017) encourage iteration in different situations to enhance students' abilities to correctly identify forces and to emphasize the notion that laws apply in different circumstances. Halloun (2007) describes the spiral approach to model building and refinement.

Hestenes et al. (1992) noted that a complete understanding of the concept of force and how it relates to motion requires its application in varied circumstances. There is abundant evidence that cycling around a concept and projecting its use by students in different situations helps build a robust understanding of the concept and how to use it.

All the main features of a force presented in section 1.6.2 are repeated throughout the Labatorials offering students and their teachers' multiple chances and situations to tackle them.

1.6.1.2 Discussions

The discussions between students and between teachers and students are imperative in the learning process and that is well supported by research. At the center of Vygotsky's (1978) sociocultural theory of learning is the idea that conceptual knowledge first appears between people on an inter-psychological plane, and then inside the learner on an intra-psychological plane. That knowledge is constructed in the social context of the classroom through language and other semiotic means. The importance of teacher–student discourse in the classroom is thus recognized, which may be considered as a form of scaffolding (Bruner, 1986; Wood, Bruner, & Ross, 1976).

Aulls (2002) observed teachers during their implementation of constructivist activities in their classrooms. He described that the most effective "scaffolding" was introduced by teachers when students failed to make learning progress in a discovery setting. He reported that students achieved all of their learning goals when the teacher spent a great deal of time in instructional interactions with them by simultaneously

> teaching content and scaffolding-relevant procedures … by (a) modeling procedures for identifying and self-checking important information…(b)

> showing students how to reduce that information to paraphrases … (c) having students use notes to construct collaborations and routines, and (d) promoting collaborative dialogue within problems. (p. 533)

Learning can be enhanced when presenting information and exploration of ideas are balanced (Scott, 1998). van Zee and Minstrell (1997) examined “reflective discourse” where students articulated their own ideas and posed questions and where teachers engaged their students in an extended series of questioning exchanges. Through a process of negotiation rather than transmission, teachers helped students develop understandings or confront misconceptions. Teachers used strategies like using reflective questioning, soliciting students’ conceptions, and invoking silence to foster student thinking. Baird and Northfield (1995) noted that in such lessons, the teacher’s intent is to encourage students to elaborate on their previous answers and ideas, to elicit what they think, and to help them construct conceptual knowledge and to scaffold their thinking. Van Zee, Iwasyk, Kurose, Simpson, and Wild (2001) found that teachers could elicit student thinking by asking questions that developed a conceptual understanding and by practising attentive silence. Teachers’ questions included those that diagnosed and refined student ideas, elicited students’ experiences, as well as those that helped students clarify, explore, and monitor their various points of view and thinking. Shore and Kanevsky (1993) emphasized the importance of teachers taking the time to respond to student’s needs and recommended practices for teachers. Their recommendations included using knowledge widely in new situations, helping students to make broad connections in memory, relating new learning to old and reinforcing and modeling metacognitive strategies.

Labatorials are centered around discussions between the students and, at different times during the Labatorial sessions, between the students and teachers.

1.6.2 Content

This part is intricately related to Section 1.2. The content of physics targeted by this study is based on the difficulties uncovered by research. The process described in the previous section is aimed at using Labatorials and RW to emphasize in part the content of this section. Here we highlight what we believe are the main ideas needed for a better understanding of dynamics. These ideas do not constitute the whole of dynamics. For example, Newton’s laws are not discussed here. However, we focus on key ideas which we deem essential in the learning process.

1.6.2.1 Force as a description of an interaction

Many researchers recommend that the force concept be taught by emphasizing forces as interactions between objects (e.g.Brown, 1989; Jimenez & Perales, 2001; Savinainen et al., 2017; Savinainen et al., 2005). Chi et al. (1994) emphasized the ontological category of forces as belonging to interaction as opposed to belonging to the property of a body. Jauhiainen, Koponen, and Lavonen (2006) conducted a study with 18 physics teachers and their students. Results revealed differences in the importance physics teachers assign to the role of interactions in mechanics. Results also revealed that students' conceptual understanding of Newton's third law was improved when teachers made explicit use of interaction as a guiding principle throughout mechanics instruction. After teaching mechanics based on the concept of interaction, students are guided to consider forces as representations of the strength of an interaction.

That a force is a description of an interaction entails the following:

1) There are at least two bodies involved in the interaction. A body cannot interact with itself, then cannot exert a force on itself. A force on a body must be exerted by another body commonly known as the agent.
2) Forces describe interactions during the time the interactions are taking place, namely in the present. Forces do not describe future interactions nor past ones. The purpose of this precision is to help students avoid carrying a force beyond the point in time when the interaction took place, as happens in the long decay model.

1.6.2.2 Contact forces and forces from a distance

At the high school level, interactions are of two types only: contact interactions (C) and interactions from a distance (D). Halloun (2007) stated:

> All forms of interactions take place at a distance in the microscopic world. For convenience purposes, and to a good level of approximation, we may assume in the macroscopic world, and by virtue of Newtonian theory, that two bodies may "touch" one another so that no distance separates them. A different force taxonomy can then be established in this world including "contact" forces of different types, each associated with particular types of agents (p. 78, emphasis in the original)

It is convenient to adopt contact forces at high school since mechanics at this level is centered on macroscopic bodies and steers away from interaction in the atomic and quantum realms. This statement is valid at the beginning of the course and should not limit teachers from exploring the lack of contact at the atomic level when the situation presents itself. This could occur during discussions with students or when answering advanced questions. At this point, it is pertinent to mention that what is considered as forces from a distance, in the macroscopic world are gravitational interaction (between a planet and a body), interaction between magnets and those between charges or charged bodies.

For contact interactions to occur, contact between the bodies (in the macroscopic view) must be present at the time the interaction is studied. For example, one identifies a contact interaction between a book resting on a table and the table, and an interaction at a distance between the book and earth. When a ball bounces off a wall, a contact interaction between the ball and the wall is only present, for a short period of time, when the ball was in contact with the wall. Whereas an interaction at a distance is present between the ball and earth throughout the motion of the ball.

1.6.2.3 Free body diagram

A free body diagram (or a force diagram) is a diagram showing all the forces acting on a body. In order to determine the behavior of a body in mechanics, one must examine the interaction between this body and its surroundings. Therefore, a free body diagram is fundamentally related to those interactions. Hestenes (1997) argues that students' ability to understand physics depends on the representational tools at their disposal. The free body diagram is an essential central step in the analysis of any situation using Newtonian mechanics. It is a representation of the identified interaction, and it sets the stage to relate the interaction to the motion of the body. The origin of the force vector is drawn on the body. Students are asked to label (name) the force vector, to identify the agent on the diagram as well as the type of force: C for a contact force and D for a force at a distance. The type of the force appears as a superscript and the agent appears a subscript (Figure 1). Figure 1 shows a free body diagram of a bloc pulled by a rope. The gravitational pull is labeled "W" for "weight", the agent is "Earth" hence the subscript, and it is a force at a distance hence the superscript "D". Similarly, the force exerted by the rope on the bloc is labeled "T" for tension and it's a contact (C) force.

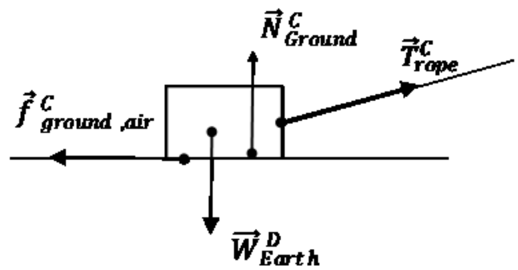


Figure 1: Free body diagram of a bloc pulled by a rope

The representation of forces in free body diagrams systematically requires students to identify, for all forces in a free body diagram, the agent and the type of force (C/D). Requiring the agent and the type of force aims at enabling students to exclude, from their free body diagrams, contact forces for which the agent is not in contact with the body. This is aimed at force as Impetus (inside the body) and the long decay model discussed in Section 1.2.

One of the common difficulties of students when it comes to forces and motion is that they assume that there is a force in the direction of motion (Section 1.2). This approach to representing forces in a free body diagram also targets this difficulty. It should be made explicit that a free body diagram should be based on the interactions and not on motion. That even if the body is moving in a given direction, a force should be included in the free body diagram only when the agent and the type of force are identified.

Savinainen et al. (2017) present an overview of several studies targeting the impact of using an interaction diagram on students' abilities to identify forces and apply Newton's Third

Law. Drawing an interaction diagram is a step that precedes the force diagram. It highlights the force as a property of the interaction and not as one of the body (Impetus). Their interaction diagram clearly helps the students identify the agent of the force it however omits that a force does not persist after the act. In our approach, we skip the Interaction diagram as a formal step however the students are required to identify the agent and the type of force. The interaction diagram can be used as an intermediate step in cases where students struggle to identify the forces acting on a body.

1.6.2.4 Resultant force and the direction and type of motion

Along with the free body diagram, students are required to draw the resultant force (not necessarily to scale, its orientation is sufficient in most cases), as well as the velocity vector and the acceleration vector. This request targets the alternative view students hold that the resultant force must be in the direction of motion. It also shows, and emphasises, that the resultant force and the acceleration have the same orientation. This also highlights that when the resultant force is in the direction of motion, the body must be accelerating and when it is not, then the body must be decelerating. In addition, it represents a pertinent integration of kinematics and dynamics. These requirements are found in numerous Labatorial activities

To draw the velocity vector, students are asked to either consider the orientation of motion and orient the velocity vector the same way or to place points for two consecutive positions and join them with a vector. Drawing the acceleration vector can be challenging for students (this is one of the difficulties listed in Section 1.2). Students often give the acceleration the same orientation as motion. To help them overcome this hurdle, they are asked to draw the velocity vector first, then verify whether the body is speeding up or slowing down. In the case where it is speeding up, the acceleration is oriented like the velocity. When it is slowing down the acceleration is opposite to the velocity. If the velocity is constant, then the acceleration is null. This approach is valid for rectilinear motion, which constitutes the large majority of all situations studied in the syllabus. For projectile motion, a more elaborate vector approach is proposed in the following section.

Drawing the resultant force can also be challenging for students. As mentioned in Section 1.2.1.2, students tend to draw the resultant force based on the orientation of motion. Students are specifically asked to draw the resultant force based on the forces in their free body diagram. In most cases, only its orientation is required.

It is worth noting that although related to the misconception discussed in the previous section (if there is motion in one direction then there must be a force in that direction), the misconception discussed here is slightly different because it pertains to the resultant force. Here students usually impose that the resultant force must be in the same direction as motion. Instead of inferring on its existence based on motion (previous section), here they infer on its orientation (of the resultant force) based on the direction of motion. Forcing the resultant force to be like motion is often obvious in situations where a body is slowing down because of friction.

Adding the resultant force to the free body diagram, the velocity and the acceleration play a role in aiding students come to terms with the notion that if the resultant force is constant then the velocity cannot be constant. Dropping an object from a certain height is a simple example of that. This approach also plays a role in helping students tackle the difficulties with the long decay model. In particular, at the peak of the vertical toss (long decay model) when the velocity reaches a value of zero with a constant acceleration. The process reveals a resultant force and an acceleration pointing downward when the velocity is null. These notions are targeted by a central activity (in the last Labatorial) where students are asked to analyse the two-way motion of a fan cart.

1.6.2.5 Vectors

Working with vectors is essential for any meaningful understanding of forces and motion. In particular, the addition and subtraction of vectors. Math courses are usually focused on constructing the sum of vectors but not on constructing the difference of vectors. In Mechanics, the sum of vectors is important for forces to produce the resultant force and the difference of vectors is important for kinematics. The displacement is the difference between two position vectors and the acceleration is related to the difference of the velocity vectors. One quick visual way to teach subtracting vectors to students is to ask them to identify the vector which should be added to the first vector in order to obtain the second one. One can start with a simple numerical application with scalars to build on the initial knowledge state. Then extrapolate to the subtraction of linear and nonlinear vectors. Subtracting non-linear vectors is important in verifying that the acceleration is along with the weight in projectile motion.

1.7 App-like approach

In this chapter, we argue that teaching and learning dynamics is still a troubling challenge for both teachers and students. That teachers struggle to integrate research findings and researchers do not adapt their findings to school settings. In our approach, we want to avoid being stuck analyzing the problem. Instead, we are trying to be a part of the solution by proposing a process that targets the most elusive part of teaching physics in high school. We are not making general recommendations to teachers; we are proposing what we believe is a robust method versus volatile propositions from research. We are providing a flexible usable process with details and justification. Duit and Treagust (2003) called to “elementarize” theories and conceptual change strategies such that they become part of teachers’ routines. Savinainen et al. (2017) showed that when given clear minimal instruction and training, teachers were able to produce good results using the interaction diagram to improve their students’ understanding of the concept of force and of Newton’s Third Law. Hestenes et al. (1992) noted that dedication and subject knowledge are not enough for effective instruction and that technical knowledge about how students think and learn is required. Angell et al. (2004) made recommendations, based on their findings, to keep students in science and technology and attract new groups, these recommendations are:

- Make the subject less demanding and work-intensive compared to other subjects, for instance by reducing the number of topics to be covered
- Emphasize science knowledge in context
- Use more qualitative/conceptual discussions and demonstrations
- Make the role of experiments more clear
- Integrate mathematics in the physics course
- Provide variation in teaching methods (p. 702)

Seidel et al. (2002) view instructional quality as “an orchestration of various didactic approaches” and claimed that a wide repertoire of teaching methods used flexibly was a relevant indicator for student learning. Gore and Gitlin (2004) argued that practitioners lacked the expertise for meaningful use of instruction tools like computer supported-learning environments, and research results have limited accessibility to teachers because of the “impenetrable jargon” used in reports. This accessibility is further limited by the lack of systematic reviews and secondary research reports that summarize results in a practice-oriented and objective way (Hammersley, 2002).

Our approach is an attempt to answer these recommendations. What we are proposing is focused on teaching forces, but it is not isolated from other parts of physics nor from science in general. We are digging deeper because one must. Every time a student is labeled as having a learning difficulty by a researcher, this researcher is digging deep. How is instruction supposed to function if all recommendations of research are general?

We are arguing that fundamental problems can be tackled with detailed ideas and processes made accessible. That instruction does not need to cover all ideas just fundamental ones. For example, the idea that a force requires an agent either by contact or from a distance. Or the suggestion that students always represent the vectors of resultant force and that of velocity and acceleration. Our suggestion extends to cyclic process where students are exposed to the same ideas under different contexts or situations to build more robust attitudes and knowledgebase. This is coherent with the complex systems approach which combines KiP and Theory-Theory discussed in section 1.2.2.4.

We used an approach, like phone apps, designed to do a set of tasks well, but not all tasks. While theories are valuable, they tend to be better in one part more than another. As if one adopting the theory must compromise and take the bad with the good. In addition, theories are difficult to apply, and they require a certain degree of know-how and training. The reality is that teachers in high school do not allow time and resources to implement the theories they read about because of the difficulty in their implementation. Such theories are, despite their proven success in research, a heavy burden for the ordinary teacher subject to institutional and academic constraints. What research offers is akin to an engineer offering a sophisticated blueprint of a machine which gives arguably good results only it has a high cost of manufacturing and operation, one needs to invest time to make it and learn how to operate it, and there are pages missing from the blueprint. This does not make it a bad machine; it makes its implementation impractical. We believe that we are offering the actual machine with a very low cost of operation and high gains. That it is easy to use and has a clear and simple manual with no missing pages. And there is one more thing; it's practically free.

One might argue that one specific tool is superior at a given task to what we are proposing. For example, a computer-assisted experiment, which could be more effective at a specific task than an activity in one of our Labatorials. We believe that what we are proposing holds enough adaptability to allow the integration of such an activity in its structure. We aimed to increase accessibility by reducing the requirements. The activities in our Labatorials require minimum standard lab equipment and a fan cart per team which can be purchased for an insignificant price compared to that of a set of sensors and processors used with computers.

Chapter 2: Theory

This chapter covers the theoretical tenets of the study. We explore instruction tools and evaluation tools used in this study. The instruction tools are RW based on course documents and Labatorials. The set of evaluation tools includes the FCI, the DFEBQ, Interviews and concept maps.

2.1 Reflective Writing

To complete an RW, students are asked to read course material and to write about it, informally, before that material is covered in class. If a student understands the material and finds it reasonable, he or she should explain why in their writings. Similarly, if a student does not understand the material or finds it unreasonable, he or she should explain why in their writings. RW finds its roots in hermeneutics which is covered in the next section then followed by an overview of RW.

2.1.1 Reflective Writing and Hermeneutics

Hermeneutics can be traced back as far as the ancient Greeks (Porter & Robinson, 2011). “Hermeneutics” comes from the Greek verb “hermeneuein”, which means “to interpret” or “to translate”. Friedrich Schleiermacher (1768-1834), hailed hermeneutics as a universal discipline, one which applies equally to all subject-areas (e.g. the *Bible*, law, and literature), to oral as well as to written language, to modern texts as well as to ancient (Forster, 2009).

In a lecture of 1829, Schleiermacher adopts the hermeneutic circle (Figure 2) as a principle of hermeneutics (Schleiermacher & Frank, 2004). The hermeneutic circle is based on the idea that to understand a text, one must understand its parts and the parts are only understood through their relation to the whole text. Understanding a part of the text can only be achieved with the text as a whole. As well as understanding the whole of the text can only be achieved through the understanding of its parts. With every turn of the circle, a reader improves his or her understanding of the text. However, it is likely that through the use of the hermeneutic circle a text cannot be fully understood, one can only improve understanding without totally achieving it.

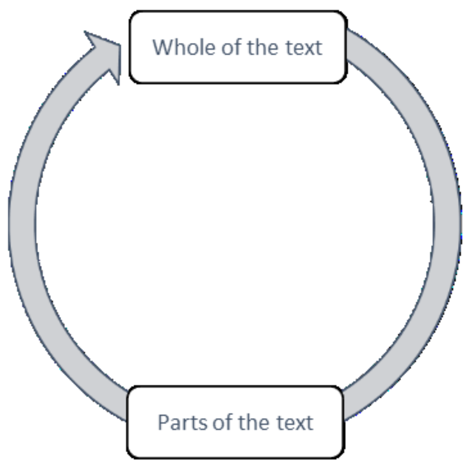


Figure 2: Hermeneutic circle (El-Helou, 2016)

In 1960, Georg Hans Gadamer introduced the modern theory of hermeneutics in his book Truth and Method (Gadamer, 2004). His approach to hermeneutics is known as "Philosophical Hermeneutics". Gadamer again emphasized the role of the hermeneutic circle and described understanding as the intersection of two horizons: the horizon of the text and that of the reader (Figure 3a) In the context of this study, the text, a scientific one, is found in the provided course documents (described in Section 2.1.4) or in textbooks and the reader is a student.

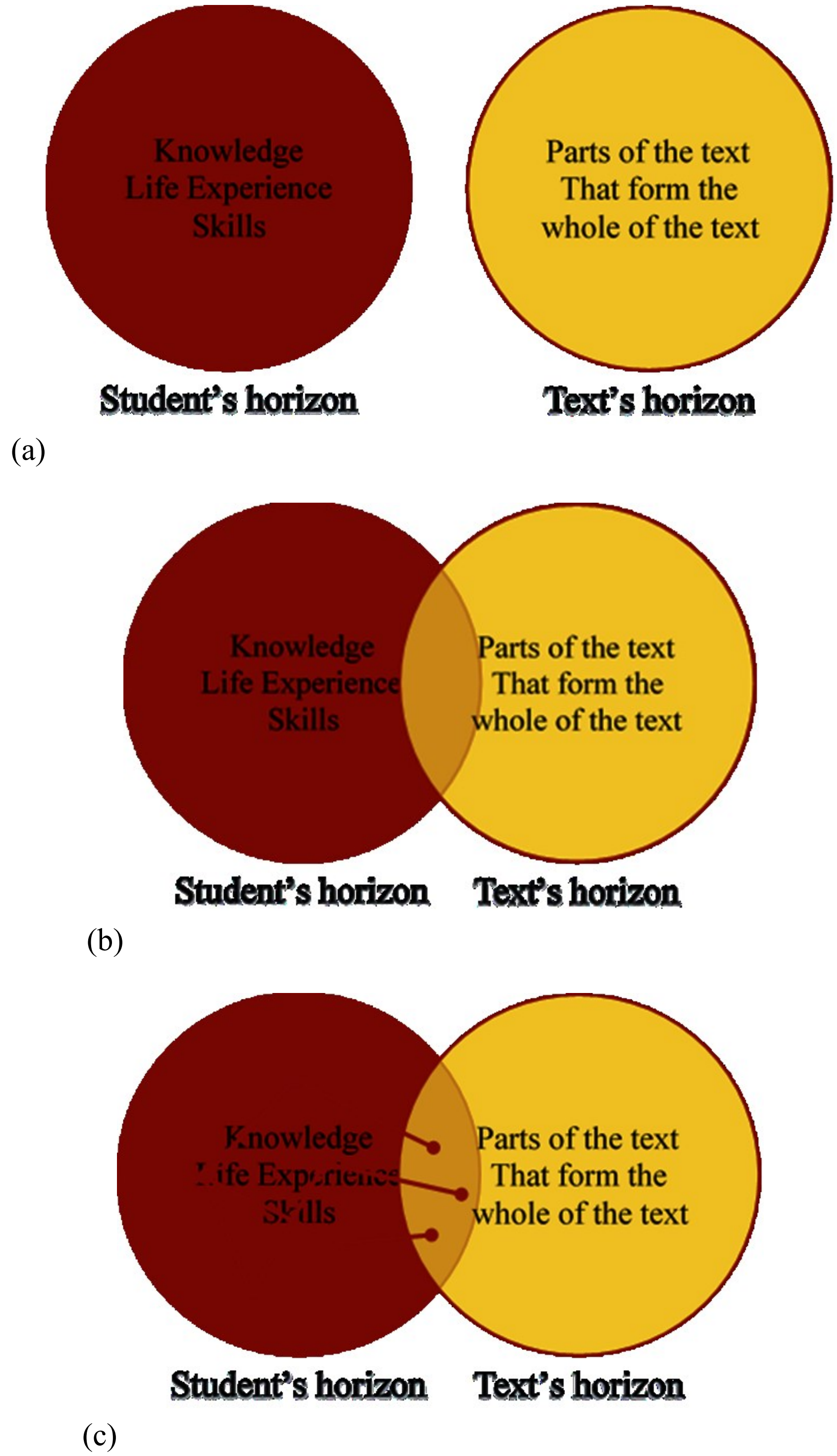


Figure 3: Horizons of the student and of the text (El-Helou, 2016)

A horizon is "the range of vision that includes everything that can be seen from a particular vantage point" (Gadamer, 2004, p. 301). The horizon of the reader has dynamic boundaries that are determined; they evolve with the knowledge, lived experience and skill set of the reader. (Eger, 1993aa) viewed the horizon as defining both our grasp and limitations. The other horizon is that of the text, “the text we are trying to interpret also has its horizon: a limit to all those meanings to which a text of this sort, employing a language of this sort, possibly could give rise” (Eger, 1993a, p. 14). If the student’s and text's horizons do not overlap, there is no way for the projections of the student to fall within the realm of the text's potential meanings, thus the attempt to reach understanding fails. An overlap, consequently, means that the students recognized parts of the text (Figure 3b). Through the hermeneutic circle, the student goes through the back-and-forth movement of interpretation, between the parts of the text and the whole of the text, which permits the student to traverse the horizon of the text and move deeper into its language domain (Eger, 1993a).

Hermeneutics extends far beyond the scope of this study. However, we would like to highlight two of its aspects that hold a special significance to the use of RW. The first one is questioning and second is connections (or relations, bonds, links). RW is designed to trigger questioning and enhance connections. According to Gadamer, understanding (text in particular) occurs with the “fusion of horizons” as a result of the reader (the student) being engaged in a hermeneutic circle. Gadamer repeatedly emphasized the central role that questioning plays in the back-and-forth process of the hermeneutic circle. “Interpretation is a circle closed by the dialectic of question and answer” (Gadamer, 2004, p. 391). “Thus a person who wants to understand must question what lies behind what is said. He must understand it as an answer to a question” (Gadamer, 2004, p. 363). “The essence of the question is to open up possibilities and keep them open” (Gadamer, 2004, p. 298).

Gadamer repeatedly emphasized the essential role of connections in the process of understanding. “Hermeneutics must start from the position that a person seeking to understand something has a bond to the subject matter that comes into language through the traditionary text and has, or acquires, a connection with the tradition from which the text speaks” (Gadamer, 2004, p. 295). The hermeneutic process is triggered by questions and understanding comes in the form of answers to those questions (Gadamer, 2004). “It [understanding] implies the general possibility of interpreting, of seeing connections, of drawing conclusions, which constitutes being well versed in textual interpretation.” (Gadamer, 2004, p. 251). “Understanding begins… when something addresses us. This is the first condition of hermeneutics” (Gadamer, 2004, p. 298).

Connections may exist, within the horizon of the student, between the part that overlaps with the horizon of the text and the rest of the student’s horizon (Figure 3c). Within the process of the hermeneutic circle which oscillates between parts and the whole of the text, other connections will form triggered by finding questions and answering them. Pre-existing connections, once not apparent to the student, may be revealed through the same process. Discrepancies may remain and the cycle is repeated. As a result, more overlap between the two horizons may occur or a broadening of the student’s horizon toward that of the text. RW represents a framework that triggers both questioning and connections as central processes in its application.

2.1.2 An overview of Reflective Writing

Reflective Writing is a tool developed by Kalman and Kalman (1996) then by Kalman (2008) to bring students to metacognitively examine and reflect on the material in their textbooks before it is discussed in class (Kalman, Aulls, Rohar, & Godley, 2008). Flavell (1976) identified metacognition as a process during which a person monitors and guides his or her own thinking while they work on a task. Metacognition through writing and its sustained use has been shown to encourage the development of this cognitive skill in students (Gunel, Hand, & McDermott, 2009).

RW is a process during which a student writes, informally on paper, his or her ideas about a specific topic (the topic is Physics in this study). A rubric (discussed below) provides guidelines for the student during the writing process. In their writings, the students can argue with themselves, question and criticize themselves or the topic.

RW is a part of the "Writing-to-Learn" movement (Connolly, 1989). Research showed that 'Writing-to-Learn' improves students' conceptual thinking; its strategies can also help students pinpoint their difficulties in solving quantitative problems (Kalman, 2001; Mayer & Hillman, 1996). McDermott (2010) showed that the "Writing-to-Learn" activity was used by students to generate and clarify their understanding of scientific concepts for themselves. Writing has been offered as one critical tool for promoting this type of scientific literacy in school classrooms (Yore & Treagust, 2006). "Writing in the science classroom is beginning to be viewed not just as a communication tool, but also as a tool to develop conceptual understanding, that is, an epistemological tool." (McDermott & Hand, 2010, p. 519).

Research has shown that engaging students in writing can positively impact their overall course performance (Cisero, 2006; Drabick, Weisberg, Paul, & Bubier, 2007; Soysa, Dunn, Dottolo, Burns-Glover, & Gurung, 2013). Larkin and Budny (2005) argued that writing can serve as a tool to improve the quality of teaching as well as to promote deeper and more meaningful student learning. Rivard (1994) showed that the use of writing enhances the learning of science content and that is intimately connected to thinking.

RW is based on the notion of "free-writing" popularized by Elbow (1973). Britton Britton, Burgess, Martin, McLeod, and Rosen (1975) placed free-writing within the notion of "expressive writing" which is a term used to refer to writing to oneself, as one would in diaries, journals and first-draft papers. Expressive writing often looks like speech written down; usually it is characterized by first-person pronouns, informal style, and colloquial diction. Fulwiler (1987, p. 21) noted that "Some writing activities promote independent thought more than others do. Expressive or self-sponsored writing, for example, seems to advance thought further than rote copying". Kalman (2008) argued that asking students to explain difficult concepts to themselves via reflection can help them identify the source of their confusion, contributing to the development of metacognitive and critical thinking skills.

Even though RW is based on the notion of "free-writing", RW is not "free-writing". A rubric (Khanam & Kalman, 2016), given in Table 1, sets RW apart from "free-writing". The rubric is provided to the students and acts as a guide of what is expected in their RWs. What is expected are questioning and connections. Section 2.1.1 established questioning and connections as key aspects of the hermeneutic circle and understanding through the fusion of horizons (Gadamer, 2004). RW asks the students to have the attitude of a "free-writer"; only the content of the writing must respect the rubric guidelines. Before coming to class, students are asked to read specific material, either provided by the teacher or material from their textbooks. After their reading, they are asked to complete an RW task, guided by the rubric and based on what they have read. Their RW products are then read by the teacher and evaluated according to the rubric. These steps are completed before covering the material in class.

Table 1: Reflective writing rubric

	Features present in the reflective-writing product	Meets criteria fully	Meets most of the criteria	Minimally meets the criterion	Does not meet criterion at all
1	Presenting the key concepts of the subject as understood by the student.	Complete Does not copy the lesson.	Covers all concepts but not really in his/her own words	Partial coverage of concepts	No concepts covered
2	Describing the relationship between the various concepts	Qualitative interpretation used to compose the relationship in the words of the student.	Surface description of Qualitative interpretation used to compose the relationship	Some attempt to compose the relationship.	Not able to interpret.
3	Student relates key concepts to his/her own life experiences	Shows clear understanding of how the concepts occur in everyday situations	Shows partial understanding of how the concepts occur in everyday situations	Mention of everyday situations without any explanation of how they relate to concepts under study in current sections	No relationships to his/her own life experiences are given.
4	Student formulates his/her own question(s).	Student realizes that there are concepts in the textbook that s/he does not understand and elaborates a clear question	Student sets out a question that is not clearly formulated	Student notes the difference between his/her own ideas and the ones in the textbooks without any discussion	No questions given

The rubric contains the criteria for student evaluation. Each criterion is evaluated on a four-point scale. The first evaluates the degree with which the reading material was included in the RW. The second and third criteria evaluate the quality of the presence of connections uncovered in the RW. The fourth triggers and evaluates questions generated in the RW. The questioning could be related to the connections between concepts or between parts of the material.

RW is not a summary of the material. It is a metacognitive evaluation of material in the manner of a hermeneutical circle. A summary could be a mechanical process which includes repetition or a form of organization of the main ideas. This process does not necessarily reflect understanding. A summary may not require reflection, questioning, nor connections between what was read. RW, on the other hand, requires that the students express the main ideas, in their own words, while interacting with the material through questioning and connection. RW "emphasizes reflective thinking about what students have read" (Huang & Kalman, 2012, p. 93).

2.1.3 Understanding with Reflective Writing

Nersessian (2008, p. 393) elaborated on the importance of relating concepts in the process of understanding:

> Concepts provide a means through which humans make sense of the world. In categorizing experiences, we sort phenomena, noting relationships, differences, and interconnections among them. A conceptual structure is a way of systematizing, of putting concepts in relation to one another in at least a semi - or locally - coherent manner… Trying to understand new experiences or how a concept relates to others can reveal heretofore unnoticed limitations and

> problems in the representational capabilities of current conceptual structures and even reveal inconsistencies with other parts.

The RW tasks, guided by the rubric, are intended to promote two key aspects of understanding which are connections and questioning. The habits of questioning and connecting concepts to other concepts and our daily lives are identified as habits of expert learners. Research has shown that differences in problem representation by novices and experts reflect differences in knowledge structure (Austin & Shore, 2011; Chi, Feltovich, & Glaser, 1981). The existing knowledge of capable students and experts is highly interconnected and new knowledge is immediately linked in many ways to prior knowledge (Larkin, McDermott, Simon, & Simon, 1980). Strong connections distinguished expert learners from average and weak learners and enhancing their connection skills improved their course performance (Austin & Shore, 1994; Shore, 2009).

It is important to note that in this study, RW is used with Labatorials which are based on inquiry in science. Questioning, promoted by RW, is the key property of inquiry in science. Inquiry generally refers to a process of asking questions, generating and pursuing strategies to investigate those questions by generating data, analyzing and interpreting those data, drawing conclusions from them, communicating those conclusions, applying conclusions back to the original question, and perhaps following up on new questions that arise (Sandoval, 2005; Shore, 2009; White & Frederiksen, 2009). “In the dialogue that takes place within inquiry learning, and through the process of asking questions about what they learn, students demonstrate improved memory of core information” (Shore, 2009, p. 165).

El-Helou and Kalman (2018) evaluated the impact of RW on secondary students’ attitudes and opinions about physics. Students were asked to complete RW tasks about mechanics prior to taking the course in class. Results showed that students were more involved in the discussions that followed and in the learning process. Results also indicated that strong students were able to filter out, on their own, most of the conceptual details of the course allowing them to focus on what they had difficulty with. Weaker students, having seen the material before coming to class, were more involved in the discussions and in group activities compared to the times when they did not complete RWs.

These findings are important and encouraging to our study. By using RW we aim at exposing students to their own ideas about forces and motion. Thus, inciting them to metacognitively reflect on their ideas and how they are related to one another. This exposure to their own ideas is then followed by an exposure to the ideas of their classmates through the activities and discussions in the Labatorials.

2.1.4 The course documents

The RWs in this study were based on course documents drafted by the researcher. There are five course documents in total. Students were asked to read the course documents and to produce a RW based on the content for each of the documents. The first course document is about the properties of a force, namely that it is a description of an interaction. The second one is mainly about the types of forces, free body diagrams. The last three course documents tackle respectively Newton's third, first and second law. Course documents are drafted with students' misconceptions and difficulties in perspective. They systematically point out common traps and offer advice on specific parts of mechanics. They are also made to be as concise as possible. They are mental road maps containing key elements for each law and concept. They offer hints and distinctions which textbooks often lack. One of the offered hints is an "oil test", a basic thought experiment used to identify the presence of friction. In order to verify the presence of friction, between a box and an inclined plan, students are recommended to imagine that there is oil (or a lubricant) between the contact surfaces of the box and the plan. If the box slides then friction was keeping it from sliding.

In the design and content of the course documents special attention was given to the decay model of the force because it combines a set of difficulties for students discussed in Section 1.2.1. The long decay model is not mentioned in the course documents. The intention was that by avoiding mentioning it we stand a better chance of avoiding it in students' minds. This is not wishful thinking. The documents systematically approach forces and their representation in a manner that shifts students away from that model and offers simple tools and mental processes to rule it out in case it is encountered. The decay model of a force is related to contact forces and not to forces at a distance. Students who adopt this model argue that a contact force, which once was exerted by one body on another, lingers on even when there is no longer any contact between the bodies, only with a diminishing magnitude (thus the term "decay"). The course documents and the activities in the Labatorial (namely the fan cart experiments, presented in Section 2.2.3) work in tandem in an attempt to either avoid the long decay model or to enable students to rule it out.

2.2 Labatorials

This part of the chapter is dedicated to the evolution of Labatorials and how they relate to other lab activities. We will also cover how we used Labatorials and focus on one instrument used which is the fan cart.

2.2.1 About Labatorials

Labatorials benefited from abundant research on effective tools aimed at making lab activities as engaging as possible for students. Here we explore how Labatorials came to be and we highlight their main advantages.

2.2.1.1 Relative background on labs

The learning of the physics content, including the understanding and application of concepts, is a common goal of physics labs (Wieman & Holmes, 2015). There is abundant criticism in literature targeting *cookbook* traditional labs (e.g.,Kozminski et al., 2014; NRC, 2013; Sokoloff & Thornton, 1997; Trumper, 2003; Wilcox & Lewandowski, 2016). Traditional *cookbook* labs direct students towards producing results without understanding the underlying physics concepts and have been heavily critiqued as being rote and inauthentic to the process of experimental physics (Wieman, 2015). Pushkin (1997) stated that when laboratory manuals dictate to students: "*what to think*, *how to think*, and *when to think*, lab activities essentially lose impact for learning" (p. 240).

Hodson (1993) described the state of mind of students taking traditional labs and the difficulties they face:

> Frequently, they are put into the position where they have to understand the nature of the problem and the experimental procedure (neither of which they have been consulted about), assemble the relevant theoretical perspective (with only minimum assistance from the teacher), read, comprehend and follow the experimental directions, handle the apparatus, collect the data, recognize the difference between results obtained and results that "should have been obtained", interpret those results, write an account of the experiment (often in a

> curiously obscure and impersonal language), and all the time ensure that they get along reasonably well with their partners (p. 100).

Arons (1993) proposed guiding instructions for learning in the physics laboratory. To promote greater effectiveness, he presented some modes of thinking and inquiry placing the laboratory as a critical part of physics teaching: (a) Observing phenomena qualitatively and interpreting observations; (b) Forming concepts as a result of observations; (c) Building and testing abstract models in light of observation and concept formation (d) Figuring out how a piece of equipment works and how it might be used; (e) Deciding what to do with a piece of equipment, how many measurements to make and how to handle data; (f) Asking or pursuing "How do we know. . . ? Why do we believe …? What is the evidence for…?", (g) Explicitly discriminating between observation and inference in interpreting the results of experiments and observations; (h) Doing general hypothetical-deductive reasoning in connection with the laboratory situations.

Hodson (1993) summed up a series of teaching steps that are intended to bring about conceptual development and modification in students and that are particularly appropriate for laboratory work:

1) Making children's own ideas explicit through writing and through discussion with other children and with the teacher.
2) Exploring the implications of those ideas.
3) Matching and testing ideas against experience and the experience of others.
4) Criticizing the ideas of others. Subjecting one's own ideas to criticism (p 109).

The need for efficient labs spawned and influenced the development of several laboratory programs. Among the most successful, the Physics by Inquiry program at the

University of Washington (McDermott, 1996), which is of particular interest for Labatorials, the Workshop Physics project at Dickinson College (Laws, 1991), and The Studio Physics (Cummings, Marx, Thornton, & Kuhl, 1999; Wilson & Redish, 1992; Wilson, Redish, & Donnelly, 1992) and SCALE-UP (Beichner, Saul, Allain, Deardorff, & Abbott, 2000). These programs developed laboratories which are learner-centered and involved students in a scientific process based on an exploration the physical world.

Physics by Inquiry (PbI), is a course for pre- and in-service teachers developed by Lillian McDermott and her collaborators at the University of Washington (McDermott, 1996). There is no lecture; students meet for three laboratory periods of two hours each per week. During these periods, students work in pairs with simple equipment; they are guided to reason through physical examples with simple apparatus and carefully prepared worksheets Students in this class work through building the ideas of topics in physics using carefully guided laboratory manuals and simple equipment. There are no lectures. The worksheets are based on research in student understanding and often use cognitive conflict (Posner et al., 1982) seen in Section1.2.2.1. This course values the guiding principle that it is more important that students gain a deep understanding of how science is made and works than to cover a large portion of topics superficially. The activities focus on specific concepts and elements of scientific reasoning such as control of variables and the use of multiple representations. The material is structured into modules allowing for flexibility in their sequencing (Redish, 2003).

The worksheets guide the students through observing and explaining physical phenomena, constructing and testing hypotheses in new experiments. Trained facilitators guide students with carefully chosen questions to find their path to understanding. At specific places indicated in the lessons called “checkouts”, students are instructed to check their results with a facilitator before going on. Although PbI is explicitly designed for preservice teachers and other nonscience majors, it is deep and rich enough that many of the lessons provide valuable ideas for the development of lessons even for calculus-based physics (Redish, 2003).

Because of the differences with traditional science classes, PbI is considered challenging for students and teachers. The goals, the structure of the learning environment, and the activities differ from those they are used to. Some students reject the idea that answers are not given, and that they have to work for them. They can put the instructor under pressure to revert to the traditional methods. The first weeks of PbI can be challenging so careful facilitation is needed to bring students value thinking, reasoning, and making sense of what they see coherently and consistently (Redish, 2003).

The implementation of PbI can be daunting for teachers because of the significant change in the learning environment. McDermott and Shaffer (2002) and the University of Washington Physics Education Group introduced Tutorials as a supplementary curriculum that can be used in conjunction with any standard introductory physics textbook. Redish (2003) argued that Tutorials in Introductory Physics is perhaps the most carefully researched curriculum innovation for introductory calculus-based physics. Indeed, it benefited from numerous Ph.D. dissertations by students in this group which have extensively investigated student difficulties with particular topics in calculus-based physics and have designed group-learning lessons to tackle those difficulties. The tutorials are designed to be used in small group sessions in which three or four students work together collaboratively. Similarly, to PbI, Worksheets guide students through the reasoning required to develop and apply important concepts and principles. These worksheets emphasize concept building and qualitative reasoning. Tutorials can be implemented to help improve student understanding of fundamental physics concepts, in a cost-effective manner, within the traditional lecture structure (McDermott, Shaffer, & Somers, 1994; Shaffer & McDermott, 1992)

Under **Workshop Physics** (WP), the PbI method was adapted for calculus-based physics in the late 1980s by Priscilla Laws of Dickinson College. Laws and her collaborators, expanded McDermott's vision to include substantial components of modern computer-based laboratory tools, including computer-assisted data acquisition and data acquisition from video. Laws also emphasized problem-solving and developing quantitative experimental skills which are goals not shared by the pre-service teacher class (Redish, 2003).

In workshop physics, lectures and demonstrations are eliminated or made minimal. Students work in a laboratory-classroom environment, where the line between classroom and laboratory is blurred. Students use computers and spend the time, which was previously spent passively listening to lectures, in direct inquiry and discussion with peers. The role of the instructor is to help create the learning environment, lead discussions and encourage students to engage in reflective discourse with one another (Laws, 1991).

The development of the Workshop Physics materials relies heavily on published physics education research. In the WP classroom, students function in groups as in the inquiry-style classroom, each pair working with a computer workstation with the computer-assisted data collection structure. Spreadsheets provide the students with tools for mathematical modeling of their experimental results. Classes are held in three two-hour periods per week. In addition to the activity guide, students are assigned readings in a text and homework problems (Redish, 2003).

Research has shown that WP is very effective at assisting students' understanding and building of concepts (Saul & Redish, 1997; Trumper, 2003).

Similar to PbI, implementing WP can be demanding as the workshop-style class may not meet student expectations especially those attending a physics class expecting a lecture with traditional homework routines. Students who are unaccustomed to group work may have trouble interacting effectively. Implementing a course like WP effectively requires that the instructor be knowledgeable of the technical requirements and open to a novice dynamic between instructor and student.

Studio Physics and **SCALE-UP** (Student-Centered Activities for Large Enrollment University Physics) adapt WP environments to a large number of students. Research-based institutions with engineering schools might have as many as 1000 students taking calculus-based physics in any particular term. Material is adapted from a wide variety of research-based sources, including Workshop Physics, Physics by Inquiry, Cooperative Problem Solving, and Peer Instruction. Students are organized into groups of three; the same groups work together in all their classes. Roles are assigned, and students received instruction both on how to work in groups and how to approach complex problems (Redish, 2003). Small (30 to 45 students) classes are set up to operate in a workshop mode with integrated lecture/laboratory sessions. There is extensive use of computers, collaborative group work, and a high level of faculty-student interaction (Cummings et al., 1999).

2.2.1.2 Labatorials

”Labatorials”, which is a word that combines “laboratory” and “tutorials” were developed by the Physics Education Development group at the University of Calgary (Ahrensmeier, 2013; Ahrensmeier et al., 2009; Ahrensmeier, Thompson, Wilson, & Potter, 2012; Stiles-Clarke & MacLeod, 2018). Labatorials were inspired by the Tutorials developed by the Physics Education Group at the University of Washington (McDermott & Shaffer, 1998).

Labatorials were introduced in 2008 to increase the interest of students, not majoring in physics, in the physics course and lab activities (Ahrensmeier et al., 2009). Labatorials were initially intended to reinforce physics concepts taught in lectures. In order to provide instant feedback to the students, a checkpoint system, similar to the "checkouts" introduced in Tutorials, was integrated into Labatorials. The checkpoints allow teachers or TAs to evaluate/guide students during the lab session as opposed to the previous system of providing feedback when the TA returns the corrected lab reports to the students a week or more after the lab session. By that time the value of the feedback was significantly reduced especially since by that time the students have moved on to the next concept (Ahrensmeier, 2013).

Students doing Labatorials typically use worksheets with several suitable activities for the duration of the lab session. The worksheets ask students to run calculations, plot graphs and do experiments, they can also include instructions for experiments and computer simulations. The focus is on concepts and how they relate to one another. Students work in teams, in an inquiry-based setup, under the supervision of the instructor or the TA who is responsible for a group of 15-20 students. There are no lab reports required after the lab session. Teams do all the work required during the lab session and hand in the completed worksheets at the end of the session. Labatorials ask teams to predict the outcomes of the experiments before completing them. After performing the experiments, they are then asked to evaluate their results and compare those results to their predictions (Ahrensmeier et al., 2012).

Predicting the outcome of a demonstration before seeing it, then reflecting on the results, have been shown to improve students' conceptual understanding (Crouch, Fagen, Callan, & Mazur, 2004; Miller, Lasry, Chu, & Mazur, 2013; Sokoloff & Thornton, 1997). Similar to Tutorials and WP, Labatorials incorporate several ideas from physics education research as well as best practices for the specific teaching situation. The learning is largely inquiry-based and involves a high degree of peer instruction (Ahrensmeier et al., 2012).

Ahrensmeier et al. (2009) argued that Labatorials changed the academic responsibility of the TA from a grader of the work done by the students to an active moderator during the work which benefits both the TA and the students. They also reported that the TAs enjoyed interacting with the students and found that it was a more valuable investment of their time. Labatorials frees extra hours for the TA which were initially invested to correct traditional labs. A teacher in high school is not a TA however the same can be said for teachers supervising labs, when it comes to the tasks described for the TA.

Labatorials emphasize the importance of the checkpoints as opportunities for the instructor to evaluate, guide and scaffold their students. Arons (1993) distinguished between "guidance" and providing instructions and answers. He noted: "…to lead them into thinking and forming of insight but not so much as to give everything away and thus destroy the attendant intellectual experience" (p. 280).

Similar to the difficulties reported by Redish (2003) in implementing PbI and WP, Ahrensmeier (2013) reported difficulties during the first years of implementing Labatorials. She noted that many students resisted having more active roles as required by the inquiry-based worksheets; most students "felt overwhelmed by questions that don't have a single correct answer". She also reported that many TAs were "uncomfortable" to grant full marks to students for the lab part of the course just for "being there and doing the work".

Labatorials are relatively new and the body of literature reporting results on their implementation is limited. Kalman, La Braca, and Sobhanzadeh (2020) compared the impact of

Labatorials on undergraduate first-year students to that of traditional labs on the performance and understanding of university students enrolled in a lab course. Results have shown that Labatorials improved students' understanding of physics more than the traditional labs, and no differences were detected between both groups on the course grade. Kalman, Sobhanzadeh, Thompson, Ibrahim, and Wang (2015) evaluated the impact of the combination of Labatorials and RW on first-year students' epistemological beliefs. Results indicated a significant improvement, of the experimental group over the control group, on two of the four dimensions of epistemology measured by the study. Sobhanzadeh, Kalman, and Thompson (2017) conducted interviews with students doing Labatorials in introductory physics courses. Results revealed increased satisfaction and involvement with the course and lab work and reduced stress levels. Ahrensmeier et al. (2012) noticed that the questions students ask changed from "is this answer correct" to "is this happening because…". Abundant evidence was reported from interviews with TAs highlighting the positive impact Labatorials had on students' and TAs' attitudes as well as anecdotal evidence from their interactions with students doing Labatorials (Ahrensmeier, 2013; Kalman et al., 2020; Sobhanzadeh et al., 2017; Stiles-Clarke & MacLeod, 2018).

Our study, as far as we know, constitutes the most detailed study on the impact of Labatorials on students' performance and understanding of physics and is the first study of the use of Labatorials in high school. It should not be surprising that using Labatorials produced positive results. After all, they are modeled after successful designs, i.e. Tutorials. We view Labatorials as an activity which holds certain traits and elements and that it has evolved depending on who is using it and where it is used. We view Labatorials as lightweight lab activities, free from lab reports, which promote discussions and instant feedback, and centered on two valuable processes of science education; inquiry and scaffolding.

2.2.1.3 Scaffolding and inquiry

The term “scaffolding” in education refers to a process during which a teacher or a competent peer, assists a learner in a manner enabling the learner to accomplish a task that would otherwise be out of reach (Collins, Brown, & Newman, 1988; Wood et al., 1976). Lepper, Woolverton, Mumme, and Gurtner (1993) described this as sustaining an “optimum” level of challenge for learners. Scaffolding requires a balance between offering support and keeping the students actively engaged in the learning process (Hogan, Nastasi, & Pressley, 1999; Merrill, Reiser, Merrill, & Landes, 1995). Reiser (2004) views scaffolding as a temporary support, which may include questions, prompts or suggestions, provided by the trainer to assist learners. The support is gradually reduced thus enabling more independence for learners.

The role of the teacher is to help students make sense of the ways knowledge claims are generated and validated as well as to mediate scientific knowledge (Driver, Asoko, Leach, Scott, & Mortimer, 1994). Scaffolding is considered a key strategy for teachers to provide students with a cognitive apprenticeship, involving students taking on more responsibility and particularly in solving complex situations with the guidance of more knowledgeable teachers or peers (Collins et al., 1988).

Scaffolding is a term introduced by Bruner (1975) and is associated with Vygotsky ’s (1978) notion of the zone of proximal development. Vygotsky (1978) describes this zone as: “*the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers*” (Vygotsky, 1978, p. 38, emphasis in the original). Rogoff (1990) describes this zone as the region of tasks between what a student can accomplish alone and what he or she could accomplish with assistance.

Vygotsky's theory is central for social constructivism which suggests learners internalize new or difficult understandings, problems, and processes through social interaction. For a social constructivist, learning is considered a social activity during which learners, exposed to new situations, are engaged in constructing or refining their knowledge through conversations and argumentations between peers and teachers (Edwards & Mercer, 1987). Students' individual constructions of meaning occur when their ideas are exposed, explored, evaluated, and supported during social interactions, such as those based on inquiry, provided during laboratory work where students discuss their ideas with peers and teacher (Driver, 1988; Mason, 1996).

Labatorials provide scaffolding between peers during the work on activities, and between students and teachers at the checkpoint incorporated in the Labatorials' structure. Kalman et al. (2020) argued that a third level of scaffolding is embedded in the sequencing of the activities of a Labatorial and between consecutive Labatorials. That the order with which the activities are presented plays a role in assisting learners in gradually building understanding as they move through the work. Labatorials are designed around maximizing opportunities for discussions between learners and between learners and teachers. Their inquiry-based activities offer opportunities for learners to test, present, and defend their ideas, thus enabling them to construct meaning.

The advantages of inquiry-based activities are well documented (e.g., Brown & Hammer, 2009; Colburn, 2000; McDermott & Shaffer, 1992). Colburn (2000) highlights three tenets for activities involving inquiry which are: asking questions, collecting data, and interpreting those data. Kalman et al. (2020) identified inquiry in Labatorials as guided inquiry (Abrams, Southerland, & Evans, 2007). Blanchard et al. (2010) describe guided inquiry where the teacher provides the source of the question or the situation to be studied, and it is up to the learners to decide how to collect and analyse the data. Blanchard et al. (2010) present an overview of research on inquiry from which they note that despite the success of inquiry in the classrooms and labs, many teachers remain reluctant to incorporate inquiry into their practices. Possible reasons are that teachers consider inquiry demanding in knowledge, time, preparations and equipment. They also noted that teachers' aptitudes for inquiry should be considered when inquiry is implemented or researched.

For social constructivism, inquiry is essential for building understanding. Exposing students to new challenging situations lead to investigations, questioning, testing and discussions which are key for constructing knowledge. Such situations help in positioning students in Vygotsky's zone of proximal development where they are scaffolded by their peers and teachers. The lightweight design of Labatorials increases the feasibility of their use by hesitant teachers. These valuable opportunities for growth through inquiry would not occur without a medium like Labatorials which harbors a considerable space for discussions between learners.

2.2.1.4 Discussions

The importance of discussions and the role they play in enhancing students' understanding and allowing teachers' scaffolding of their students' learning process has been introduced in Section 1.6.1.2. Here we emphasise the benefits of small group discussions. Labatorials offer two levels of small group discussions: the first is between the students during their work on the Labatorials' activities; the second is between the students and the instructor at the specified checkpoints. What we mean by discussions extends beyond simple conversations. It could include argumentations, planning strategies, presenting and defending ideas, which all can be as scaffolding elements.

Weaver (1998) found that students favor laboratory or "hands-on" activities, which can promote conceptual change when combined with discussions and reflections. Hogan et al. (1999) analyzed the discourse patterns and collaborative scientific reasoning in peer and teacher-guided discussions. They found that, without the teacher present, peers talked more, showed more complex reasoning and better justified and synthesized the information. The presence of a teacher brought a more efficient resolution of ideas which reduced the complexity of reasoning.

An essential part of the discussions at the checkpoints is the instant feedback the instructor can provide. Ericsson, Krampe, and Tesch-Römer (1993) found that developing expertise requires guiding feedback while the learner is explicitly practicing all components of this expertise. Effective formative assessment allows teachers to situate their students' knowledge state and to adjust their instruction accordingly. It also allows students to express their thinking, obtain instant feedback from the teacher, understand any expected learning outcomes, and move their learning forward (Black & Wiliam, 2009). Discussions are central for the elicit and challenge approach (Posner et al., 1982) and the bridging technique (Clement & Rea-Ramirez, 2008). The elicit and challenge approach is based on the idea that, through generated discourse over chosen situations, students' alternative ideas are elicited and confronted. Students are then brought to a mindful state where they find them incommensurable. The bridging technique uses teacher-guided discussions and analogies to connect the target case to an anchor case. The anchor case describes an initial knowledge state where students' conceptions are in alignment with the scientific view. The target case is the situations representing a higher knowledge state which is what the teacher wants the students to understand. Whether students prior knowledge is viewed as "coherent" or "fragmented" (Section 1.2), theories about those views agree that connections between the concept or pieces of knowledge represent a higher order of knowledge. That these connections shift students from the naïve view of physics to the expert view. Bridging and confronting ideas, which rely heavily on discussions are argumentations, are the predominant approaches to tackling either fragmented knowledge, misconceptions or difficulties.

Lattery (2016) highlights the importance of environments and situations that harbor free discussions between the students and teachers and the time to comfortably conduct these discussions. That small group discussions are essential for model building and refining. The interventions' opportunities offered to the teacher at the checkpoints are akin to those offered during model co-construction (Clement, 2008). Lattery (2016) describes the process of model co-construction as:

> A teaching methodology that engages teachers and students in an active partnership of scientific model building. The instructor often prompts students to develop new model elements and model criticism of their own; and at the opportune moment during the instruction, the instructor introduces new modeling elements or model criticism for the students to consider (p. 243).

Similarly, at the checkpoints, teachers evaluate the progress of the students, prompt them with key questions either to further push a conclusion they reached or to trigger a change in the direction the group is heading.

2.2.2 How we used Labatorials

Labatorials in our study were used in high school in combination with RW with the main purpose of evaluating their impact on students' understanding of forces and motion. Kalman et al. (2015) combined Labatorials and RW in their study with university students to measure their impact on students' epistemological beliefs. Even though both studies use a combination of RW and Labatorials their target population and aims are different. Another distinction in the way we used Labatorials in our study is with its relation to the physics course. Labatorials in introductory physics courses were used in conjunction with lectures as a unit of the course designed to reinforce and develop notions seen in lectures. In our study, similarly to PbI, lectures and lab work were fused in Labatorials. Apart from certain clarifications regarding the representation of forces and free body diagrams most of the dynamics course was covered in Labatorials which were followed by traditional exercises and homework tasks. We believe that this process better suites the name "Labatorial" which implies an "instructive" lab. At this point, it is pertinent to note that Labatorials are preceded by RW tasks. This means that students walk into a Labatorial session already knowing what the topic is which arguably helps in fusing lectures and labs.

A Labatorial in our study is typically is based on a worksheet made of 3 or 4 activities (with one bonus activity just to keep a team or two working if they finish before the end of the session). Activities include conceptual questions, calculation problems as well as instructions for experiments. Sketching velocity-time graphs and corresponding position-time graphs can also be required as well as free body diagrams. Labatorials are fun, lightweight activities that allow students to discuss freely and even make mistakes without fearing failure. Labatorials are open-book, even open-web activities; furthermore, they don't have to be completed in one lab session. They can be easily extended to the next session if need be.

Students in our study are asked to complete an RW task about the upcoming Labatorial. Unlike traditional labs, our Labatorials do not require lectures preceding the lab. They are intended for students to discover and test their knowledge of concepts while doing the lab. They are not designed to enable students to better crunch numbers and procedures. Labatorial activities or topics of discussions are intended to introduce or improve understanding of key concepts. They mimic real-life situations or are inspired by historic experiments like those of Galileo.

The sequencing of activities within a Labatorial and from one Labatorial to another emphasize the process guidelines (Section 1.6.1) which are progression through repetitive varied exposure while harboring discussions. The activities were designed by the researcher under a guided-inquiry approach. The content of the activities focuses on students' difficulties identified by research (Section 1.6.2). Ahrensmeier et al. (2012) recommended, for successful use of Labatorials, that a full set be provided with clear sequenced activities and TA training. This recommendation was followed in the design and sequencing of the Labatorials in this study.

The teacher-student ratio in our study was significantly higher than that reported in studies conducted at university levels. In our study, one teacher supervised a class of about 25 students. Whereas, for other studies with Labatorials (or with Tutorials and WP) the ratio was one instructor to about 15-20 students. This is somewhat understandable considering that there are no TAs in high school that could be hired to reduce the teacher-student ratio. The high teacher-student ratio was taken into consideration in the design of the activities and allotted time per Labatorials. Labatorials were tested during a pilot study conducted during the academic year preceding the start of the study and were found manageable if the number of teams per class is limited to seven. Participating teachers in our study were recommended to limit the number of teams in their classes to seven. As we already mentioned, work on the same Labatorial may overflow one lab session to the following one which could cover time restrictions or unforeseen delays (not uncommon in high school).

A typical Labatorial cycle in our study follows the steps below:

- Before doing a Labatorial, students are asked to read the course document and complete an RW task about what they read. For example, if the Labatorial is about Newton's First law, then the students are asked to read a section of the course document concerning Newton's First law and write about this Law.
- A classroom discussion about the first law would be helpful to cover the main ideas of the law and to answer students' questions. This step is not necessary, for Labatorials are about discussions between group members and with the teacher. However, El-Helou and Kalman (2018) recommend classroom discussions following RW tasks. Their study conducted with high school students revealed that discussions following RW tasks improve students' attitudes toward learning physics.
- Designate a lab session (or two) for the Labatorial about Newton's First Law. Students work in groups that range between two and five members. We believe that the ideal number of members in a group is 3 and that the maximum number of groups per teacher is 7.
- Follow up with conveniently chosen exercises that promote understanding and course requirements.
- Assign the following RW and the corresponding Labatorial.

Labatorials are not rigid structures, they may be adapted to a course, school requirements or lab equipment. In many cases, students may use their smartphones to take photos and videos (in slow-motion) of the motion of bodies. Because the lab equipment used is minimal, setting up Labatorials requires little effort and time. Lab reports are not required from the students after completing a Labatorial. They simply must submit the completed Labatorial document.

Students often realise, during their discussions with the teacher at the checkpoint of a given Labatorial activity, that the answer they have given is wrong. The teacher must allow the students to rectify their answers before submitting them. The teacher may choose not to discuss all aspects of the Labatorials with the students provided the main ideas are discussed. This serves two purposes: The first reduces the time spent with every team on the checkpoint. The second is that with activities targeting the same concepts, the teacher may choose to discuss one activity with the students and leave the other similar activity entirely to them. After submission, the teacher can evaluate their answers on the activity that was not discussed with the students thus providing the teacher with extra criteria to evaluate the work of each group.

2.2.3 The fan cart

An essential lab element in our Labatorials is the fan cart, which is a cart propelled with a battery-operated fan mounted on it (Figure 4). It was initially introduced by Holton, Rutherford, and Watson (1981) to produce a horizontal motion with a constant acceleration. Morse (1993) made modifications to the cart and proposed using the fan cart in different experiments while changing the mass it carries and the speed of the fan. Morse (1993) also proposed launching the fan cart with a negative velocity which results in a two-way motion of the cart. In this case, the cart is pushed against the force of the fan, the cart then moves in the direction it was pushed while slowing down then reverse directions. Lattery (2016) offers an extensive analysis of the use of the fan cart and recommends its use in lab activities. He details students' patterns of answers to the one-way motion and the two-way motion produced by the fan cart.

With more recent fan carts, like the ones we used in our study, a light sheet of plastic (usually transparent) can be mounted on the cart facing the air blown by the fan. The fan cart is considered a basic lab tool. Different variations of the fan cart can be easily found on the market and at specialised lab equipment providers. For our pilot study, we (proudly) manufactured our own fan carts. For the study, identical fan carts were purchased and provided to participating teachers.

Figure 4: The fan cart

We used the fan cart for several reasons: (a) it can produce a horizontal uniformly accelerated motion with a tangible constant force heard with the humming of the fan which duplicates the motion of a body falling freely vertically downward (Lattery, 2016; Morse, 1993); (b) when used with the plastic sheet it offers an interesting and stimulating application to Newton’s Third Law; (c) the two-way motion of the cart replicates the behavior of a body vertically tossed upward (Lattery, 2016); (d) the two-way motion of the fan cart offers analysis possibilities of the long decay model of the force (Lattery, 2016) discussed in Section 1.2.1.

The decay model is a central target in the design of the Labatorials, and in the sequencing of their activities. Similarly, the decay model directed many of the points included in the course documents even though it is not explicitly mentioned.

A discussion targeting the decay model of a force was included in the teacher workshop (Section 3.5). The goal of the discussion was to emphasise the role of the points listed above in avoiding or excluding the model. More details on how the decay model surfaced and treated are given in chapters 4 and 5.

2.3 The force Concept Inventory

The Force Concept Inventory (FCI) was initially published in 1985 as The Mechanics Diagnostic Test (MDT) (Halloun & Hestenes, 1985). The MDT was refined over the following years to emerge with its best-known version, the FCI, which was developed by David Hestenes and his collaborators at Arizona State University (Hestenes et al., 1992). The FCI is a survey composed of 30 multiple choice-items designed to probe students' conceptual learning of Newtonian dynamics. It focuses its items to cover forces, Newton's laws, two-dimensional motion with constant acceleration, identification of forces, impulsive forces and vector sums. A high school student takes about 30-40 minutes to complete the FCI.

The FCI is probably the most widely used force concept survey (e.g., Fazio & Battaglia, 2019; Hake, 1998; Savinainen & Scott, 2002). Hake (1998) published the collected results of the FCI on over 6000 students from 60 classes. Hake used the pre and post-test scores of the FCI to calculate a normalized gain (g) which established a standard to which other studies are compared. Hake found that traditional teacher-centered courses produce a low gain which is less than 0.3. Interactive engagement courses which are student-centered produce a medium gain

($0.3<g< 0.7$) or a high gain ($g >0.7$). Redish, Saul, and Steinberg (1997) and Saul and Redish (1997) confirmed Hake's results with classes using Tutorials and WP. These results add support to the idea that g is one plausible measure of the overall gain.

We used the FCI to gather information on students' understanding of forces and motion which can be compared to data from other studies. It was important to choose an instrument with well-documented data analysis. We are aware of certain critiques in the literature targeting certain FCI items and how clusters of FCI items are formed and analyzed, namely that the FCI was designed under the "coherence" perspective discussed in Section 1.2.1.1 (e.g., Henderson, 2002; Savinainen & Scott, 2002; Scott & Schumayer, 2018). The analysis of those critiques is beyond the scope of this study. Our use of the FCI and the comparison of the obtained data are mainly limited to the statistical realm and based on Hake's normalized gain (g).

2.4 Epistemological Beliefs Questionnaire

The Discipline Focused Epistemological Beliefs Questionnaire (DFEBQ) was used in a study combining Labatorials and RW to evaluate the impact of that combination on the epistemological beliefs of students in introductory physics at the university level (Kalman et al., 2015). Their results have shown a significant change in two of the four dimensions of beliefs measured by the DFEBQ. We were interested to see if similar results could be obtained with high school students. The results are discussed in Section 4.1.4.

Schommer (1990) initiated a quantitative approach to research students' personal epistemology for learning. Since then, the link between learners' epistemological beliefs and their performance has been an active topic of research. Researchers have been examining relationships among students' epistemology beliefs and other academic constructs. Research has shown that how students view the structure of knowledge affects their academic performance and attitudes toward what they learn (e.g., Brownlee, Walker, Lennox, Exley, & Pearce, 2009; Phillips, 2001; Schommer-Aikins, Duell, & Barker, 2003). Hammer and Elby (2003), in a research on how to tap the epistemological beliefs' resources to help physics students learn, found evidence that students who had absolutist epistemic orientation, who perceived knowledge as a collection of discrete facts that had to be memorized and recalled or recognized did not succeed academically. Whereas those who held evaluative perspectives and adopted constructivist learning approaches were successful.

Hofer (2000) adapted the DFEBQ from Schommer's (1990) Epistemological Questionnaire (SEQ). The DFEBQ contains 27 items that measure personal epistemologies of learner along 4 identified dimensions: Certainty/Simplicity of Knowledge; Justification for knowing: Personal; Source of Knowing: Authority; Attainability of Truth. The answer format of the items is a five-point Likert scale which ranges from "Totally agree" to "Totally disagree".

The DFEBQ has been widely used, analyzed and evaluated (e.g., Karabenick et al., 2007; Muis, Duffy, Trevors, Ranellucci, & Foy, 2014). Our interest in the DFEBQ relates to the comparison of the results obtained by our study with high school students to those obtained with university students presented in Section 4.1.4.

2.5 Presenting the concept map

Educational researchers have developed various ways to diagnose students' understanding. Interviews and surveys, for example, have been used to monitor and evaluate students' conceptual development. Multiple-choice diagnostic tests are easy to administer and can provide timely feedback (Treagust, 1988, 1995). The image of the learner's knowledge provided in such tests is limited to the choices they offer. It may also be difficult to find an instrument that matches the instruction content (Griffard & Wandersee, 2001; Nyachwaya et al., 2011). Interviews generally offer a detailed view of the learner's knowledge structure and reasoning process (Clement, 2000). However, interviews are time-consuming and require careful interpretation which limits their use to a relatively small number of students.

Even though interviews constitute a central method for data collection in our study and we used one of the most recognized surveys of forces and motion (the FCI), it was pivotal for our study to supplement them with a concept map which is a formative assessment tool capable revealing the connections students make between concepts. Well-structured knowledge is regarded as an indicator of the quality of understanding (Mintzes, Wandersee, & Novak, 2005). Interviews can reveal such connections, but they can only be conducted with a small number of students (12 in our study). The focus of the FCI is on revealing students' understanding of concepts and laws and the misconceptions they hold, but not on uncovering connections between concepts.

The concept map (CM) is a graphical assessment tool adopted by education researchers for arranging the structure of conceptual knowledge (Novak, 1990; Novak & Cañas, 2008; Novak & Gowin, 1984). In science education, concept mapping is viewed as a method to evaluate students′ knowledge construction (e.g., Baxter, Elder, & Glaser, 1996; Edmondson, 2005; Liu, 2004; Stoddart, Abrams, Gasper, & Canaday, 2000). CMs allow students to integrate new information by connecting it to existing ones and offers a telling visual aid for them and their teachers (e.g., Conradty & Bogner, 2012; Schwendimann, 2015).

Won, Krabbe, Ley, Treagust, and Fischer (2017) offers three approaches for completing CMs. In the first approach, students are asked to construct a CM from scratch where it is up to the students to decide the elements (concepts) and how they are connected. The second approach, teachers provide both the structure of the map and a list of concepts, then it is up to students to “fill in the blanks” this is the most rigid form of approaching a CM. The third approach, teachers provide a list of concepts and ask the students to establish the connections between the provided words. The goal of the third approach to CMs, which is the one used in our study, is to verify if students are making expected connections. Students participating in our study were given many concepts and instructions on how to complete a CM, as well as an example of a CM. No training on how to complete a CM was offered to the students.

McClure, Sonak, and Suen (1999) elaborated on and compared six main methods for evaluating concept maps: structural, holistic, and relational, each with or without referring to a master map. The master map is completed by the instructor, and it represents a reference map to which the students’ CMs are compared. Upon considering the reliability, validity and time requirements for each of the six methods, McClure et al. (1999) ranked the relational with master map as the most convenient method, followed by the holistic with master map. The relational with master map evaluates individual connections made by the students as compared to those in the master map. The holistic method with master map considers the global structure of the CM as compared to that of the master map. The CMs in our study were evaluated using both relational with master map and holistic with master map. Details of the process and the results are provided in Section 4.1.5.

As noted at the beginning of this section that a CM can be used as a formative instruction tool or and as an evaluation tool. In our study, it was used as an evaluation tool.

Chapter 3: Methodology

This chapter presents details on the methodology followed in this study as well as a description of the participating students and teachers. It highlights processes used to collect two types of data: a) qualitative data collected from participating students through semi-structured interviews and from their teachers through workshops and discussions; and b) quantitative data collected from participating students' answers to standardized tests and from their concept maps, RWs and Labatorials.

3.1 The pilot study

During the academic year 2016-2017, the researcher conducted a pilot study using Labatorials and RW with a sample of 62 students frequenting a private school in the Montreal area. The purpose of the study was to check the structure of the activities in the Labatorials, the wording used in those activities, the sequencing of Labatorials and RW, and the time taken by each Labatorial. Comments gathered from the students, and from the researchers were used to tune the presentation of the activities and the time distribution across all the Labatorials. The pilot study showed that the fan carts used, which were constructed by the researcher, were not reliable. Better fan carts were purchased, tested and distributed to participating schools for use in the study.

3.2 The study - An overview

The main purpose of the study is to evaluate the use of a combination of tools on high school students' understanding of dynamics. The tools used are:

a) Course documents targeting the main concepts and laws of forces and motion. There is a total of five documents. The first two documents cover mainly the concept of force, the types of forces and most commonly used forces. The last three documents cover the three laws of motion of Newton. The course documents were written by the researcher and are based on existing literature and on the researcher's experience in teaching high school physics.

b) RW. Students were asked to complete five reflective writing tasks. Each task is based on one of the course documents. Each RW task was followed by classroom discussion.

c) Labatorials. Each RW task and classroom discussion was followed by a Labatorial covering mainly the same topic as the course document and the RW.

Table 2 shows the topics covered in course documents and their respective RWs and Labatorials. A sample course document is provided in Appendix A and a sample Labatorial is provided in Appendix B.

Course Document	**RW topic**	**Labatorials topic**
Force	The force	Force diagrams
Famous forces	Friction force	Force diagrams and the Sum of forces
Newton's third law	Newton's third law	Newton's third law
Newton's first law	Newton's first law	Newton's first law
Newton's second law	Newton's second law	Newton's second law

Table 2: Topics covered in the course documents, RWs and Labatorials

In a typical cycle of this study, presented with more details in Section 2.2.2, students start by reading course documents, then they complete, as homework, an RW on what they have read. The RW is followed by a classroom discussion managed by the teacher, then followed by the corresponding Labatorial. There is a total of five cycles. The first cycle is preceded by pretests (which include the FCI, the Epistemological test and concept map) and pre-interviews. The last cycle was followed by the post-tests (the same as the pretest) and post interviews.

Before continuing with the procedural details of the study, we would like to tackle head-on what we believe could be a concern for the reader. The course documents give the students results from the very beginning which could be considered as contradictory to what the inquiry is based on. One can argue that countless research has shown that “telling” the students what the scientific laws and concepts are, has practically no influence on them understanding them. The following addresses these concerns.

3.3 The study- A justification

Many ideal processes are extremely difficult to implement in school environment which is subject to many constraints discussed in Section 1.3. Such constraints may corner teachers into lecture-type instruction just to fulfill these requirements at least in the eyes of the administration, the parents and the students. This study offers an alternative, although less ideal when compared to the requirements of educational theories, it remains applicable across most educational structures. Structures that include teachers in classrooms or labs, with students put there by their parents, in institutions called schools run by what is known as administrations and follow what is known as curriculum, which is imposed by a governmental entity. A process at the end of which students might have to pass some form of a standardized exam.

The course documents expose misconceptions or difficulties identified by literature. They offer (or tell) students the final result and offer pointers to assist them in the process of construction of knowledge. If the learning process is akin to a journey, then the information presented in the course documents is akin to one informing a traveler to a destination and provides advice on how to navigate the path. Our approach lies somewhere in between pure constructivism and lecture-type approach. In constructivism, students are confronted with situations where they construct their knowledge unassisted from the ground up. Conversely, lectures tell students what they should know. Literature has shown time and again that simply telling the students what the right concepts are, be it in books, websites or lectures, is not enough for them to integrate that knowledge. This is not the process nor the goal of this study. Even though we start by presenting, in the course documents, what we believe is scientific knowledge, in other words, we are telling them, the process does not end there. It is followed by an RW where students are invited to evaluate that knowledge and their attitudes towards it. Thus, triggering metacognitive processes empowering students to take control of what they learn and what makes sense for them. In this process, a student looks at the presented knowledge and weighs it with respect to pre-existing knowledge. Weighing new knowledge involves questioning both new and old knowledge as well as identifying connections, creating new ones or breaking old ones. The RWs rarely leave students at ease with new knowledge and often triggers a quest to fill gaps between what is presented as scientific knowledge and what the students think scientific knowledge is. Even if some students are at ease with the new knowledge, that state of ease can be a false state simply because the students were superficial in their analyses of the new knowledge and how it compares to pre-existing knowledge. Be it a state of filling gaps or peaceful bliss, RWs are followed by classroom discussions and by Labatorials. The classroom discussions naturally filter out what the students think they grasped and focus on what they didn't perceive. The selection of discussion topics in a classroom is made by the students when they mention unresolved situations or questions. The topics can also be chosen by the teacher who already consulted the RWs of the students and, based on their needs, compiled topics or examples for discussions. Classroom discussions elicit situations either proposed by the students or by the teacher. Each situation can trigger another cycle of questioning and connection which could bring the students closer to understanding and integrating new concepts and laws. As interesting and useful as they may be, classroom discussions are seldom broad in spectrum, tackling mainly general aspects of the laws and concepts and some useful details. These traits can be enough for some students; however, they may not be helpful for strong and weak students. The strong tend to examine minute details of a situation which are difficult to cover in a broad class discussion. Weak students often lag what is being discussed and avoid asking their questions when they see that the class has moved on beyond what they needed at the beginning of the discussion (El-Helou & Kalman, 2018). To cover these situations and other similar situations, one-on-one discussions are needed, or discussions in smaller groups. Labatorials provide these needed small group discussions between the students on the one hand and between the students and the teacher on the other hand.

Labatorials can follow classroom discussions or can immediately follow RWs. In addition to containing activities designed to cover common misconceptions related to forces, motion and Newton's laws, their checkpoints are valuable opportunities for teachers to monitor and scaffold students' learning. Each activity is a chance for students to cycle through their learning process, be it in using and strengthening already created connections or forming new ones. As simple as it may seem, activities can also be reminders for students to tackle gaps in their knowledge. Students uncover gaps in their knowledge all the time, but do not immediately act to close them. It is possible they wanted to close them but got distracted or just forgot about it, or closing the gaps was simply put off to settle other matters. When reminded of those gaps in activities, students often seize these opportunities to ask questions or be involved in the discussions with their peers and teacher to close these gaps. They don't have to put them off because the time is dedicated to those particular activities. The small group discussions give more opportunities for members to tailor the discussions to their needs. They allow the strong to examine the details and the weak to go back to the basics. As will be discussed in the following chapter, the checkpoints discussions not only allow teachers to better monitor students and scaffold their learning but also to discover sparks and genius analyses, from both strong and weak students, that otherwise were left unnoticed.

We agree with the argument that simply telling the students what the scientific knowledge is, does not lead to understanding that knowledge. At the same time, we are not sending them on a quest for that knowledge without telling them what the ultimate goal is. In one conversation I had with my students when I was completing my masters, I explained that when they discover knowledge on their own it becomes truly theirs. I explained that when we tell them what knowledge is, they will forget it; however, if they find it on their own through inquiry, then it becomes a part of them, and they would seamlessly integrate it into their knowledge system.

In our approach, we are describing the target of the quest which is reassuring to the students. They know at least which direction they should be heading toward. Some talented or advanced students are even already there. We are also providing tools (course documents and RW) and an open environment (like classroom discussions and Labatorial) to accompany the students along their journeys. We are also warning them about difficulties, which is analogous to warning travelers about traps or pits along their way. If there is a dangerous pit where the students could fall, as their guides we should warn them about it. Especially if falling in that pit would cost them significant effort to get out of. It would simply be cruel not to warn them. If the pit is small, then letting them fall is indeed recommended. As a result, they will learn form their own experience which would be the best way to learn, in a way this is inquiry. We are offering a journey with a known destination and major pits identified, but not the path they could take. They still have to navigate a right path to the destination which holds its discoveries. One can tell students that, in the absence of air, bodies fall the same way regardless of their mass. They can even see it in a video documentary. That does not mean that they understood it. However, they know what the end result is, but they might lack conviction. The process offers conviction.

3.4 Participants

Participants to the study are high school students in the greater Montreal area completing the required physics course in their last year at school before moving on to CEGEPs. A CEGEP is an academic institution (some are technical), unique to Quebec, which carries grade 11 high school students, for two years, to the university level (or three years to a technical competence). The course covers mechanics and optics. The study of Newton’s Laws of motion is the main part of the dynamics section of the course. The dynamics section is preceded with an introduction to vectors and the study of kinematics. Both kinematics and dynamics tackle only bodies in translation. Bodies in rotation are covered in physics courses in CEGEPs. A total of 210 students participated in the study over two academic years: 2017-2018 and 2018-2019. Participants came from 3 private schools in two of which the teaching language is French and in the third one it is English. Participants were 53 males and 157 females. Table 3 shows the distribution of participants across academic years, languages, teachers and genders.

Table 3: Distribution of 210 participants over school, teacher, language and gender

			Participants						
			2018-2019		2019-2020				
School	Language	Teacher	Male	Female	Male	Female		Total	
1	English	1	14	10	24	19	67	English 89	210
		2	9	13	0	0	22		
2	French	3	6	7	0	0	13	French 121	
3	French	4	0	48	0	60	108		
		Total	29	78	24	79			
			107		103				
			210						

Four teachers (teachers 1 to 4 in Table 3), all males, participated in the study in its first year. Two taught in the English sector (teachers 1 and 2) and two in the French sector (teachers 3 and 4). Teacher 3 dropped out of the study in the second year because his teaching load changed, and he was no longer the physics teacher at the school. Teacher 2 embarked on the second year of the study, but he had to drop out a few weeks later because of personal circumstances. Luckily for the researcher and the study, students of teachers 2 and 3 accounted for the smallest portion of participants.

The qualitative part of the data was to be collected from interviews conducted with numerous participants of the study. It was decided to interview two participants for every teacher in each year of the study. Having four teachers in the first year and two in the second year resulted in interviewing 8 students in the first year and 4 in the second for a total of 12 students. More details on the interviews and the selection process are given in Section 3.7.

3.5 Teacher workshops and follow-up

Four teachers including the researcher were involved in administering the study. It was deemed necessary to conduct a workshop for participating teachers to unify their approach. Two workshops were planned and prepared by the researcher before the beginning of the study: the first workshop occurred on a Saturday of November 2017 and included the researcher and two other teachers; the fourth teacher could not attend because of family obligations. In the week that followed, the researcher conducted another workshop with that teacher to go over the main points which were discussed with the other teachers. A workshop was organized before the first year of the study but not before the next year. All participating teachers had already attended the workshop and were familiar with the process. The following points represent the main ideas and processes targeted by the workshop:

<u>About the study in general</u>

- The goal of the workshops is not to show teachers how to teach but instead invest their teaching skills in combining Labatorials and RWs in a designed process to teach dynamics in high school.
- The failures of teacher-centered lecture-type courses and the successes of inquiry and student-based approaches.
- The importance of standardizing approaches for the sake of obtaining comparable results while maintaining teacher freedom of classroom and management and attaining course objectives as required by the schools.
- The data collection and administering Labatorials and RWs. Particularly completing five RWs in a specific order with specific topics from the course documents, where each RW is

followed by a specific Labatorial. Participants answers to standardized tests (described in Section 3.7.2) are collected prior to and following the RWs and Labatorials. The FCI questions should remain confidential and were not to be shared with the students. Teachers were asked to avoid discussing them with their students.

- Pre and post interviews will be conducted with participants randomly selected from a pool of volunteers (detailed in Section 3.7).
- Presenting the study to the students and their parents/guardians, namely the opt-out option (discussed in Section 3.6). Maintaining that the identities of all participants and teachers are kept confidential while asking all participants to write their names on their RWs and Labatorials. This measure in necessary for proper data analysis. Teachers were asked to collect all RWs and Labatorials which could be used for data analysis.
- Providing students' grades on the physics course or a grade assigned by teachers for each of their students describing their performance in the physics course. It is worth noting that two teachers agreed to provide their students' grades. The other teachers wanted to avoid what they estimated would be a breach of confidentiality based on their school policies. They generated and provided instead a grade describing their students' performance in the physics course. Whether the grade was provided by the teacher of the actual course grade, both types will be referred to as course grade.
- Teachers were provided with fan carts and their batteries as well as hard copies of the FCI questionnaire. Teachers were granted access to a drive folder containing the other documents related to the study (Labatorials, consent forms, …).

<u>About RW</u>

- RWs are mainly based on the provided course documents. They are assigned as homework which should be submitted before the material is covered in class. They are partially intended to shift the classroom from teacher-centered to students-centered. The purpose is to make them think and write about the material to be covered. Whether what was written is right or wrong, just by writing its mission accomplished.
- Introducing RWs to students as a personal opinion about the material. Emphasizing avoiding summaries. Students should be discouraged to repeat the material but instead to write what they think about the material they read. The RW rubric was presented and discussed as well as samples of what counts as good RWs and as summaries.
- Grading RWs is recommended while assigning a low coefficient. This measure encourages students to take the RWs more seriously.

<u>About Labatorials:</u>

- Labatorials are based on inquiry, they encourage discussions between students and teachers and do not require a lab report. Labatorials emphasise and expand the material in the course documents and which was already the subject of an RW task.
- The teams must be formed by the teacher and must be kept throughout the study. Plan a maximum of 7 teams of ideally 3 members each of different academic levels. With 7 teams, the teacher has enough time to maintain follow up.
- The estimated time for each Labatorial is 90min. If needed, teachers may extend the duration of a Labatorial. They should be viewed as an extension of the course, particularly as if it is the course being covered through inquiry. This was meant to reassure teachers that the time

invested in Labatorials integrates well in their course work and does not constitute an addition to their workload nor to that of the students.

- Labatorials are comprised of several activities separated by checkpoints. The concepts, laws and misconceptions targeted by each activity are presented in a teacher guide provided with the Labatorial. Checkpoints offer the teacher the possibility to verify that the purpose of the activity was met. They are also opportunities for discussions and to elicit and confront certain misconceptions and to push analysis even further with advanced teams.
- It is recommended to sign the checkpoints along the dotted line indicating that the activity was discussed with the team. It is also recommended that the teacher take quick notes of what was discussed at the checkpoints. These notes are valuable when it is time to grade the Labatorials.
- The differences between traditional labs and Labatorials were discussed, and the advantages of the latter were highlighted. At the same time, Labatorials were not presented as a miracle solution, yet more as a practical solution allowing teachers to reach their course requirements while promoting understanding and inquiry. Labatorials are situations offered to students where learning outcomes can be reached by asking students chosen questions to uncover connections and misconceptions.
- The first two Labatorials, which are mainly about the concept of force and force diagrams, were discussed in detail to give teachers an idea of what to expect during a Labatorial. Special attention was placed on defining forces and their labelling in free body diagrams. Namely:

  a) that the force is a description of an interaction between two bodies and b) the addition of the agent (body exerting the force) and the type of force (contact force or a force from a distance) to its representation in free body diagrams. The importance of identifying the agent of a force was emphasised as an essential step in drawing free body diagrams as well as a valuable clue in overcoming misconceptions. One particular misconception was discussed which is the decay model of a force. Because of its projected usefulness, teachers agreed to require this notation (highlighting the agent and type of force) from their students at least in the part related to the study. One teacher argued that when it comes to numerical questions, particularly those related to Newton's second law, this notation of the force could be cumbersome. It was then agreed on that in the type of problems where a vector analysis of forces and calculations are required, the students may use a simple notation of the force without the agent and type.

- Because of their importance to the study, the teachers discussed the activities related to the fan cart of Labatorial 3- Newton's third law and Labatorial 5-Newton's second law. Particularly in Labatorial 5, the relation between the two-way motion of the fan cart and the motion of a body tossed vertically upward (freefall).

<u>About forces and the FCI</u>

- The FCI it is a multiple-choice questionnaire which tackles the conceptual aspect of Dynamics and Newton's laws. It is comprised of 30 questions and takes about 40 minutes to complete It does not require the use of calculators. The questions are given in a paper form and the answers are collected on an online digital platform. The FCI must be kept confidential, it cannot be digitalized, and it cannot be used, in part or in full, in quizzes, tests nor exams. The owners of the test require that all hard copies be destroyed upon completion of the study.

- The FCI should be treated as a formal test. Documents, Pens, papers, calculators are not allowed during the test. Only computers are allowed during the test to access the online form to submit their answers.
- The FCI questions should not be discussed with students before nor after the test, especially not between the pretest and the post-test. If a student asks a question in class about a similar situation, the discussion is acceptable only without direct reference to the test questions.

About the Epistemological test (DFEBQ)

- It is comprised of 27 items measuring, on a 5-point Likert scale, students' opinions and attitudes about knowledge in physics. The test is online based and takes about 15 minutes to complete. Teachers were recommended to ask their students to complete it in class, under their supervision, or to be completed as homework.
- A 28th item was added to the test by the researcher asking the students to evaluate their level in physics. The purpose of this addition it to look for correlations between how the students view their level with their actual level provided by their course grade.

Workshops were followed with individual phone meetings with participating teachers during and following the study in its first year. Valuable comments and instances from teachers were gathered during these phone meetings which are discussed in the following chapter. These phone conversations also offered the researcher the opportunity to add focus to the purpose of the study and help teachers align their efforts toward its goals. Questions were answered and methods and situations were discussed. these conversations proved to be of great value for all teachers including the researcher. By comparing timelines, students' reactions to certain parts and difficulties and triumphs encountered, teachers obtained a better grasp on how to manage the different elements of the study. The elements range from, analysing and grading RWs and managing classroom discussions to students' reactions to Labatorials activities and managing the discussions during checkpoints.

Why that order of Labatorials for Newton's Laws: the third, followed by the first then the second?It is worth noting that participating teachers wanted to start with Newton's second law. They argued that covering the second law in the early phase of dynamics would allow them to cover more exercises related to the mathematical applications. Such application would help prepare their students for the requirements of Physics courses in the coming years. The researcher argued that the proposed sequence is preferable for the following reasons:

• Starting with the third law would be best because of how useful it is in helping students draw better free body diagrams. Drawing free body diagrams is the first part of any dynamics course and the third law plays a key role in identifying the forces in play and their agents. Also, the discussion of the third law includes a general discussion on how the mass of a body impacts its motion. The role of the mass in the third law surfaces when examples like the firing of the cannonball are discussed. Particularly when one argues that the speed of the cannonball is greater than that of the cannon, not because the force exerted on the cannonball is greater but because the mass of the cannonball is less than that of the canon. This example highlights how the discussion of an aspect of the third law (forces of the same magnitude) can introduce the role of the mass which is essential for the other two laws. Finally, both free body diagrams and the third law offer great opportunities for the teacher to discuss the resultant force (or net force, or the sum of forces) on bodies especially when they are at rest. The resultant force is central to the other two laws.

- Teaching the first law before the second one is preferable for mainly two reasons. The first reason is to use both the impact of the mass and the resultant force, introduced in the third law, to cover examples highlighting the first law. Namely how the mass of a body is related to its inertia as well as how a resultant force of zero is not an indication that the body is at rest. Such examples are covered in the course documents and are again emphasized in the activities of Labatorial-4. Particularly the first activity discussing the use of seatbelts and headrests in a car and the third activity about the astronaut throwing an oxygen tank in space. The second reason is that teaching the second law before the first might lead to eclipsing a conceptual aspect of the first law by its mathematical form. That aspect is that when the net force is zero the acceleration is zero which leads to one of two possibilities: either the body is at rest or it is in a uniform rectilinear motion (i.e. having a constant velocity). This aspect of the first law is mathematically represented by F=ma of the second law. From a conceptual standpoint, such ideas are better discussed before being placed in a mathematical form. Besides, F=ma poorly represents the concept of inertia, i.e. the idea that the tendency of a body to resist change is directly related to its mass, especially when the net force is zero. Finally, if it is argued that the second law should be covered before the first, one might counter-argue that doing so renders the first law pointless. Indeed, with a couple of neatly chosen examples, one can show that the entirety of the first law is encapsulated in the mathematical relation of the second law. But doing so does not help the students analyse situations when there are no numbers to crunch for example: why is it that when a tablecloth is suddenly pulled, the plates that were once on it fall on the table and not on the ground? The use of F=ma to justify what happens in this situation seems overcomplicated at a high school level. The same goes for the use of seatbelts and headrests in a car. Such situations are better covered before reaching F=ma and should be emphasised mathematically when it is reached.

3.6 Presenting the study

The study was presented to the students as a part of their normal course work. A letter (Appendix C) introducing the study was sent to the students and their parents/guardians. The letter highlights in part the purpose of the study, the data collection, and that the identity of all participants will remain confidential. The letter also stated that participating in the study does not require any additional efforts from their part. Specifically, that they are considered participants unless they wish to withdraw. To do so, they have to fill and sign the Opt-Out form (provided with the letter to the parents/guardians) at any time during the process. It was also made clear that withdrawing simply means that their answers will not be included in the data collected. They have to complete all the required tasks as a part of their course work, like any other student participating in the study. For the record, none of the students opted-out.

A part of the workshop offered to the teachers was dedicated to presenting the study to the students. All teachers agreed to:

- Dedicate class time to presenting the main objectives of the study and to answer students' questions and concerns. Namely that it is intended to improving teaching physics from which future students and teachers will benefit.
- Emphasize the importance of answering truthfully to maintain the validity of the results. Teachers were specifically asked not to mislead the students into answering in a way that projects that the process is beneficial when they don't find it to be beneficial. That they don't have to please anybody. That their responsibility is to answer truthfully to benefit future

students and teachers and that by doing so everybody benefits including the study, the researcher and research in education in general.

- Maintain that their identities will remain confidential even if they were asked to include their names with their answers. That this measure was necessary to maintain a follow up on an individual's answers.
- Maintain that they can Opt-Out at any time if they wish to do so, but that they still have to do the same work just like those who did not opt out.
- Ask the students to volunteer to sit for two interviews which will be audio recorded: the first one would last for about 15min and will be conducted at the beginning of the study. The second one would take place after the conclusion of the study and would last about 30 min. From the pool of volunteers in a given class, two students will be randomly selected for the interviews.

3.7 The interviews.

Standardized tests can be very efficient when it comes to identifying certain knowledge or skills, their range however is limited when it comes to uncovering thought patterns, especially those related to analysing forces and motion and the misconceptions they entail. Semi-structured pre and post interviews were planned to complement the data from administered tests and probe the mindset of students as well as their thought patterns.

3.7.1 The interview questions and interviewers

The questions of pre and post interviews are provided in Appendix D. The interview questions probe students' opinions and attitudes toward learning physics, RW, Labatorials and how forces are related to motion. A particular focus of the post interviews was given to the fan cart experiment. The two-way motion of the cart described in the second activity of Labatorial 5-Newton's Second Law is a central experiment because it resembles to free fall and because it combines all laws and the decay model. It was estimated that discussing this experiment with students will add valuable insight into how they view the relation between force and motion. The purpose of the pre-interviews was simply to create a baseline with the interviewee and will not be discussed in this thesis. For logistical ease, it was decided that teachers conduct the pre-interviews and that all the post-interviews be conducted by the researcher. The main reason behind having the same person, the researcher, conduct the post-interviews is the fan cart experiment. Even if all the teachers are competent to manage the interview questions with their respective students, one teacher might probe or view students' answers differently than another teacher. It was then important to approach the post-interviews with uniformity to enable the comparison of results. In addition, the researcher is the most qualified to tackle questions in the context of the study.

3.7.2 The selection of interviewee

In the process of presenting the study to the students, described in Section 3.6, teachers invited students to volunteer for the interviews. Out of a pool of volunteers for every teacher, two students were randomly selected. A total of twelve 12 participants (4 Males; 8 Females) were interviewed; 8 (3 Males; 5 Females) from the first year of the study and 4 (1 M; 3 Females) from the second year. Table 4 shows the distribution of the selected participants for the interviews per teacher, year and gender of participants. Selected participants for the interviews and their parent/guardian were asked to sign a consent form (Appendix C). The form reminded participants that the interviews will be audio-recorded, that their identities will remain confidential and that they can drop out at any time without any repercussions.

Participants selected for the interviews

Table 4: Participants selected for the interviews

			Participants selected for the interviews			
			2018-2019		2019-2020	
School	Language	Teacher	Volunteers	Selected	Volunteers	Selected
1	English	1	7	2(M)	6	2(1M;1F)
		2	6	2(F)	0	0
2	French	3	4	2(1M;1F)	0	0
3	French	4	8	2(F)	5	2(F)
		Total	25	8 (3M;5F)	11	4(1M;3F)

All interviews (pre and post) were conducted with the participants at their respective schools, during school days. Before the post interviews, the researcher reminded the interviewee of the importance of their contribution to the study and that their answers will help future students and teachers only if they are truthful.

3.8 Pretests and post-tests.

The FCI (Section 2.3), the DFEBQ (Section 2.4) and the Concept map (Section 2.5) were used in pre- and post-test. Students' answers to the questionnaires were gathered via online forms. Students were asked to complete the concept maps as homework either on paper or on a computer and then submit it to their teachers.

3.8.1 The Force Concept Inventory

To administer the FCI, teachers dedicated class time before the study and following the study. Papers questionnaires were given to the students and their answers were collected via an online form. Students were asked not to write anything on the questionnaire and to had it back after submitting their answers. Students required between 30 and 40 minutes to answer all 30 items of the FCI.

3.8.2 The Discipline-focused Epistemological Beliefs Questionnaire

Teachers had the choice to either ask their students to complete DFEBQ in class or as homework. Teachers 3 and 4 dedicated class time for this task, whereas Teachers 1 and 2 gave it as homework to their students. All participants accessed an online form containing both questions and the answer form. to the 27 items of the DFEBQ a 28th item was added which asks students to evaluate their academic level in contrast to their classmates. The purpose of adding the item was to obtain how students view their level and compare it to what their actual level is. Adding the item at the end of the questionnaire did not affect the original order of the questions nor their wording which would not prevent us from comparing our results from other studies that used the test. Participants needed 10 to 15 minutes to answer all 28 items.

3.8.3 The Concept Map

A concept map is a visual representation of the connections students make with the concepts they encountered. Students were provided with a document (Appendix B) containing a set of 11 concepts about forces and motion and trajectories. The document also includes instructions on how to complete a concept map and an example of a concept map not related to forces and motion. Students were asked to complete the concept maps as homework. Other than the instructions on the document no formal training was given to the students on how to complete a concept map. Participating teachers were also asked to complete the concept map to generate the master map.

Chapter 4: Results

This study aimed to evaluate the impact of combining RW with Labatorials on high school students' understanding of dynamics. In this chapter, we present the results gathered from the interviews, the standardized tests, and the concept map. The fan cart experiment conducted in the interviews will be discussed in detail in Section 4.1.5.1.

Full transcripts of the post-interviews are grouped in Table 19 in Appendix E. The interviewed participants are identified with a five-character code. For example "MEL38". The first character is for the gender of the interviewee. The letter "M" is for male and "F" is for female. The second character is for the language of instruction. It can either be "F" for French or "E" for English. The third character is a letter to identify the interviewee. The fourth character identifies the teacher. Since four teachers participated in the study, the fourth character can either be 1, 2, 3 or 4. The fifth character is for the academic year during which the interview was conducted. The value "8" is associated with 2017-2018, and the value 9 is associated with 2018-2019. The example "MEL38" of an interviewee would be interpreted as a male, studying in English, code-named L and taught by teacher 3 during the academic year 2017-2018.

Every quote from the interview transcripts in Table 19 is accompanied by a number that indicates its row in the table. The purpose of the number is to allow the reader to easily locate the quoted part in the table (the table is relatively large). All quotes include the student code and its row (identified by the letter "R") in the table and have the following form: "MEL38-R92". All the interviews were transcribed in their original language, either English or French. When quoted, passages from the French interviews are translated into English and included in the body of this thesis along with their reference to the table.

4.1 Combining RW and Labatorials

The study results explored in this section highlight the impact of combining Labatorials with RW on students' understanding of dynamics.

4.1.1 The interviewed students

In this section, we present students' responses related to Labatorials and the combination of RW and Labatorials. Even though their responses do not necessarily reflect that their knowledge of physics improved they indicated their general satisfaction with both Labatorials and RW and their combination. How these tools improved their understanding of dynamics might surface in this section, it will however be detailed in following section of this chapter.

The interviewed students repeatedly expressed their appreciation to both Labatorials and RW and to the role they played in helping them understand dynamics. In expressing their appreciation of Labatorials, students compared them to traditional labs even though they were not specifically asked to do so.

> FFL38-R138 & R150: … because before, it was always easy, we had classes, we learned things, then I did the labs, but I did not question myself, I applied the formulas, it was routine. With Labatorials I questioned myself and, in the end, I liked it…. I always liked physics, but doing Labatorials, it made me ask questions, then like, it made me want to go into physics later.

MES19-R165: I liked that we were supposed to consult the teacher while doing the lab cause… since it was as we were learning these, but for other classes I mean, your obviously not supposed to talk to the teacher in the lab and they can't answer certain questions, but I liked that for this, you went to see them before you went on to the next step. The next step probably involved something you needed from the previous step.

Many interviewees appreciated the hands-on aspect of Labatorials which goes beyond simply applying formulas seen in the course. Namely, the opportunities the activities offered in the Labatorials to test and discuss the connections between concepts they read and wrote about in their RWs.

FFC48-R139: It helps us better understand our ideas. In addition, it is a good way to learn the material. Because we are analyzing, and we are creating connections.

MEM18-R133: [Labatorials] ….was one of the most enjoyable important parts for me in the whole course, even though I'm not inclined toward the experimental side or aspect of physics, because it destroys some of the ideas I have, but in terms of importance for learning it has a huge significance.

Students also expressed their appreciation of the checkpoints and the chances they offered them to verify and deepen their understanding of the material.

MET18-R146: Yeah, … so we were put into groups, and then we had group discussions, in relation with the experiments that were going on, that way like, ideas were like, put forward and we could like discuss it, which was the most logical seeming one, and I think like group discussions really worked for me, I

> like that style of learning. And after like, we came to the best possible conclusion for this experiment, and then we went to the teacher, and then like we had like free time with him, so if we didn't understand something he could really explain it to us, in depth, whereas in a lecture form you wouldn't be given this much attention.

To the question: Did the RW activities help you meet your expectations of Labatorials? A student in the post interview answered:

> FES28-R172: Yeah because we read about the concept, we wrote about it, and when I wrote about it, I sort of like learned about the concept more, and when I went to the Labatorial I would like, see the concept in action. Yeah it helped.

Another student went to describe the mental process between RW and Labatorials. The RW being understanding on her own and Labatorials being deepening her initial understanding only in groups. She called it "group understanding".

> FFD49-R180; R48: … ..I think it [RW] helped me, but without me really knowing, because it already showed what I understood and what I did not understand and seeing that everyone had done them [RW], everyone almost knew what they understood or what they did not understand and the fact that we are able to discuss… Like me, if I didn't understand someone would explain it to me while we were doing the lab, I have the impression that this understanding there, my idea of collective understanding, it really was thanks, a little bit, to reflective writing…When we look more at the Labatorials, it was really a common understanding, we helped each other…we understood the material together, then with the help of the teacher, it was always appreciated

> when the teacher was able to put forward what we had to focus on to understand everything else.

While all interviewees appreciated Labatorials, one top student expressed her doubts that Labatorials helped her reach course requirements, particularly when it comes to preparing students for exams. When asked whether Labatorials were a waste of time she commented:

> FEU28-R135: I don't think they were a complete waste of time, but there were moments where I felt like I don't understand like, what it's supposed to lead me towards, like it's harder, because of the way I guess, our school is constructed, You are evaluated based on whether or not you can complete or pass your exam, and I personally, am not able to put down, what I'm able to experience in real life, down on paper and use what I experienced in real life into an exam and a test. So, the Labatorials didn't particularly help me, what usually helps me is exercises because they actually leave me, to like, to know what to do during an exam.

When asked what she would change in Labatorials, she recommended integrating analysis of traditional exercises along with analyzing real-life situations. It is worth noting that some students dislike interactive teaching methods and prefer lecture-type courses. (Cullota, 1992; Laws, 1991). Laws (1991) reported that some students resented having to teach themselves everything and preferred lecture-type instruction. That the time invested in working for interactive courses affected other courses. The interviewee did not go as far as to resent Labatorials. However, she complained that the time spent on Labatorials did little to help her prepare for exams. She recognized their value but doubted again their ability to prepare students for traditional tests.

> FEU28-R159: I think that maybe, I mean I understand like your point of view or your goal of this, for us to be able to apply this in real life and learn ourselves through real life motions, and I think it's a really good goal. But like as students, it's just harder for us to apply this in school, I guess.

Students were asked whether the course changed their ideas or understanding of the relation between force and motion. Students shared examples of interesting things they learned.

> FFS49-R59: Yes for example, a bicycle and a car colliding, for me it was obvious that the car had a lot more force on the bicycle, whereas, not, it is really, the effect which is observed, is due to the mass, but the force is equivalent, of the car on the bicycle and of the bicycle on the car.
>
> MET18-R62: I learned that, when we were doing the free body diagrams that's like, the force is to be drawn independently from the motion and that motion is like only to be considered later, I'm not sure how to really explain it, but when we were doing the free body diagrams we were always drawing forces and, at the beginning we were like, it was like confusing to distinguish between like, the actual forces and the motion of the object. But after the Labatorials it was like more distinguishable, which was the motion, and which was the force behind the motion.
>
> FFL38-R66: … Before I thought that, motion always took place when we pushed it, and when we are still pushing it, but after the course, I realized that motion can be pushed, but after that, the "force of the inertia" (the student means inertia) will make it continue, even if there is no more force applied...

4.1.2 The teachers

Comments and propositions were gathered from participating teachers during and after completing the study. Teachers shared their reactions and those of their students to the different tools and processes employed in the study.

All teachers reported that the RWs were very liked and appreciated by students. Teachers noticed that students were ready when they walked in class, they knew what to expect and they were ready to tackle the activities. The prior knowledge they had was overall beneficial. The students were mentally in the right state. Teachers also recognized the importance of the RWs for Labatorials which wouldn't be so effective without RWs. Teacher-1 called the RWs pre-labs. For the teachers, the RW offered a glimpse into the minds of their students and revealed how they thought about the material. Teacher-2 shared that he doesn't systematically get to see what his students are thinking but RW gave him this chance. They particularly liked that RW specifically asks students to link to their knowledge to real-life situations as well as to other knowledge. Teachers 1 and 2 appreciated the storytelling part in RW and said that it was "particularly beneficial". It is the part of RW where the students talk informally about what they know of the material and how it relates to their existing knowledge and everyday situations. Teacher-2 felt the students were honest in their storytelling because they were expressing their ideas freely, as if unfiltered by how they should say things to get a grade. It was just them and the physics. This teacher also insisted that his students go back and read their RW after the Labatorials to evaluate the progress in their thought patterns. This was a recommendation with the other teachers. Teacher 3 noticed that strong students enjoyed RWs. He also noticed that students that usually study for the grade, without much attention to meaning, found it difficult to generate examples for the RWs inspired by their daily lives. It was like a “wakeup call” for them to put more effort into understanding what they read and wrote about.

Teachers found that Labatorials were a good balance between equipment and knowledge. That with simple equipment they were able to go after a significant amount of knowledge and misconceptions related to forces and motion. From their students’ reactions, teachers found that their students enjoyed doing the labs. Teachers 1 and 3 noticed that their students did not complain about Labatorials, which is what usually happens in traditional labs. The experiments were simple, easy to understand yet far reaching in terms of knowledge. The stops in the Labatorials were conveniently distributed. They allowed room for the students to discuss freely about the experiments and to get instant feedback from their teachers. Teachers also noted that not having a lab report was certainly relieving for them and their students. It allowed them to go through the Labatorial almost stress-free. Teacher-3 noted that Labatorials would significantly help novice teachers. Because of their structure and guidance, they introduce misconceptions about the concept of force and the main details that should be tackled with Newton’s laws; they guided learners on how to approach these misconceptions.

After the first year of the study, all teachers reported that the Labatorials exceeded their assigned durations. Labatorials 2 and 5 even took double the estimated time. Teachers agreed that the prolonged duration was mainly due to discussions being too engaging. Students extensively exchanged ideas amongst themselves before asking the teacher to verify their work at the checkpoints. Even at the checkpoints, the discussions with the teachers were equally engaging and stretched the Labatorials time. Even though Labatorials can span more than one session, extending their duration affected teacher planning. Additionally, teachers 1 and 2 had course sessions of 65 minutes and Labatorials were designed for sessions of 90 minutes.

Teachers didn't mind spreading a Labatorial over two sessions, only they found that the time remaining from the second session was not too useful to do anything other than the Labatorial. They ended up dedicating 130 minutes to complete a work requiring 90 to 110 minutes. The extra time allowed many teams to complete the bonus challenge question at the end of a Labatorial. However, the teachers would have preferred to use that extra time differently. Teachers 3 and 4 also noted that Labatorials exceeded their designated durations, but because they had sessions of 90 minutes, they did not encounter the problem teachers 1 and 2 encountered. The time remaining from the second session of 90 minutes was enough to move on with the course.

Teachers 1 and 2 recommended designing a shorter version of Labatorials with a duration of 60 minutes while keeping the longer version. Thus, offering teachers the option to choose the most convenient version depending on the duration of their sessions. These teachers argued that designing a shorter version of the Labatorials will only make them more appealing to teachers interested in using them because they would fit better in their planning. For the following year of the study, a shorter 60-minutes version for four of five Labatorials was introduced to the study. The Labatorial that was not reduced was Labatorial 5 -Newton's second Law which is the one containing the two-way motion of the fan cart experiment. Due to its importance to the study, it was deemed worthy to dedicate the necessary time to this Labatorial. The reduction in the other Labatorials did not affect their initial goals. It simply reduced the number of applications targeting those goals. Teachers 1 and 4 used the reduced version of the Labatorials in the second year of the study and reported that the duration was enough to complete the work. The excess time needed for the fifth Labatorial was not cumbersome because it was expected.

Teacher 3 found that knowledge flowed intuitively through the order of Labatorials. He particularly appreciated having Newton's second law last. However, teachers 1 and 2 would have preferred, as mentioned in Chapter 3, starting the laws with the second one, as he had done before the study. After their first year of participation, they argued again that covering the second law earlier in dynamics would give them more opportunities to tackle numerical exercises. Often during their discussions with their students, teachers felt that they were dodging questions about the second law. Questions which they usually did not get, and as a result did not have to dodge. However, they were ok with it, for the sake of the study. They even mentioned that they would go back to teaching the second law before the other laws once the data collection is completed. Only they would do it with Labatorials, especially Labatorial 5, simply because of the two-way fan cart experiment.

All teachers expressed their appreciation of the fan cart experiments for what it brought to the lab work and the discussions in both lab and classroom. Particularly using the fan cart as a model for vertical motion. Teacher 1 even said: "if all must go and be changed for whatever reason, this experiment must stay". He noted that it threw the students off balance and forced them to think about the smallest details of forces and motion. He described the surprise of many of his students when they realize that both the two-way motion of the cart and that of a body tossed vertically upward are almost identical. The experiment forced them to reconsider what initially seemed to be obvious, and which turned out to be wrong.

Teacher 3 mentioned (also noted by Teacher 4) that students had different attitudes toward the Labatorials depending on their study habits or academic level. These teachers noticed that students who usually mechanically apply what they saw in the course, just to get the grade, found Labatorials interesting and eye-opening. The activities offered by the Labatorials and the open discussions caused these students to discuss their ideas and intelligibly connect them. Teachers had the impression that these students were creating relations between what was usually fragmented knowledge. Teachers recalled countless moments during the discussions where these students manifested joy and pride that they understood a distinction or because they connected two concepts. These teachers also reported that certain top students were annoyed by Labatorials, as if they were under pressure in their duration. One top student of Teacher 3 questioned the purpose of having the students guess what the outcomes of experiments are. The student asked the teacher to simply tell them what they are supposed to reach instead of having them discover it on their own. A similar situation occurred with teacher 4. Also, two top students, among those interviewed, expressed their frustration with certain aspects of Labatorials which could relate to the comments cited above. One of the interviewed students was bored by what she referred to as excessive discussions of simple stuff. The other interviewed student felt that Labatorials were occupying time which can be invested in practice problems which are more helpful for the coming year. It seems that most top students find Labatorials helpful, some find them boring because they already understood, some feel pressured because it is up to them, the strongest of the group, to produce results and make connections and even guide the connections made by others. Top students are usually competent and goal-oriented. They are also expected, especially in group work, to help those in need of guidance. These circumstances create redundancy for top students seen over many courses and activities, including Labatorials. Some top students are frustrated by that and express their frustration. One way to overcome this frustration is a design offering challenging situations for top students from which they can learn and grow.

Teacher 3 mentioned that students were mostly doing thought experiments in Labatorials 4 (about Newton's first law) even though the necessary equipment to do the experiments was provided. He also noted that students had a bit of difficulty grasping the relativity of motion when it comes to the headrest and the motion of the head when the car is hit from behind, the body moving forward and the head moving backward. Students were repeatedly imagining that the head will hit the steering wheel at the impact and not after the impact. Teacher 4 confirmed this pattern in students' responses. Teachers had the chance to tackle this detail during the checkpoints. It would help to describe the whole sequence of the motion of the body after the car is hit from behind and then ask a specific question about the instant the car is hit. Then ask about the following instant when the head hits the steering wheel or the airbag.

Teachers appreciated the Labatorials' focus on the force diagram in different situations. They reported that the addition of the agent and the type of force to the force label was ok at the beginning and it became more fluid as the work evolved. All teachers particularly appreciated the situations where the resultant force and the direction of motion were simultaneously required. They stated that their orientations triggered very interesting and rich conversations on and off the checkpoints. Especially the situations where the resultant force is opposite to the direction of motion and the situations, in Labatorials 5 (Newton's second law) where the orientation of the acceleration was added to the diagram.

Teacher-3 proposed adding, to Labatorial 2 (about forces and vector sum), activities involving an inclined plane and an elevator to highlight the effect of the normal force. This addition would also help teachers cover these common situations in a physics course. Teacher-3 specified that these situations are typical requirements in a physics course in high school and beyond. That covering such situations plays a double role. On the one hand, they could trigger interesting discussions during a Labatorial. On the other hand, the Labatorial is helping teachers cover the course material, which count as classic, nonetheless required.

Teachers were asked to describe Labatorial sessions and the evolution of the discussions. A common unplanned outcome reported by the teachers is that, in addition to the discussions within teams, discussions in between teams occurred often. Teams would discuss and compare their answers and analysis with neighbouring teams. Sometimes a team would listen to what the teacher is discussing with other teams and get inspired by these discussions. Some teams would even say to teachers at the checkpoints that they understood a section because they overheard the teachers' discussions about that section with the other teams.

Teacher-4 noted that two top students came to him before the fifth Labatorial and asked whether teams are going to remain the same for the rest of the year. They were somehow worried to keep the same teams for the rest of the school year. They said that they would prefer to change teams because they feel that the analysis always falls on their shoulders and that it would be good to change teams and change the dynamics of the discussions. They added that it would be good to see what members of the other teams know and benefit from their experience and input and not always hear the same people and the same ideas. Teacher-4 answered that within the context of the study it was agreed upon to keep the same teams across all participating schools. That the teams can change for the rest of the year for the parts of the course not covered by the study.

4.1.3 The FCI results

The analysis of the FCI results will be discussed in two parts. One part of this section will cover the global scores of participants. The second part (Section 4.2) contains an analysis of answers to selected items related to the fan cart experiment.

Answers to FCI questions were collected from 210 participants. A total of 37 participants (17.6%) were excluded from the FCI data analysis because they lacked either the pre-test scores or the post-test scores. The total scores on both pretest and post-test of 173 participants were used to calculate a normalized gain as described by Hake (1998).

The normalized gain *g* for a participant is the ratio of the actual gain *G* ($G = S_f - S_i$) to the maximum possible gain G_{max} ($G_{max} = S_{max} - S_i$):

$$g = G / G_{max} = (S_f - S_i) / (30 - S_i)$$

Where S_f and S_i are respectively the final (post) and initial (pre) scores. A score is obtained by awarding 1 point for a right answer and 0 point for a wrong answer for each of the 30 items of the FCI. The maximum score S_{max} a participant can achieve on the FCI is 30. For example, if a participant scored 10 on the pretest ($S_i = 10$) and 22 on the post-test ($S_f = 22$) then the normalized gain g for that participant would be g= (22-10)/(30-10)= 0.6 indicating that the participant gained 60% of the maximum available gain. Hake (1998) analysed average normalized gains (<g>) from over 6500 participants and defined:

"High-g" courses as those with (<g>) > 0.7;

"Medium-g" courses as those with 0.7 > (<g>) > 0.3;

"Low-g" courses as those with (<g>) < 0.3.

Hake (1998) found that high and medium gain courses are associated with Interactive Engagement (IE) teaching methods and low gain courses are those associated with Traditional (T) teaching methods. He defined IE methods as (p. 66):

> designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussions with peers and/or instructor.

He defined IE courses as those making extensive use of IE methods. He also defined traditional courses as:

> Those reported by instructors to make little or no use of IE methods, relying primarily on passive-students lectures, recipe labs, and algorithmic problem exams.

The data from our study (N=173) gave an average normalized gain (<g>) value of 0.36 (SD=0.34). The obtained <g> indicates a medium gain as calculated by Hake (1998) which is similar to those obtained when IE methods are used in teaching physics (Hake, 1998). The <g> for every teacher is presented in Table 5. The <g> of both Teachers 1 and 4 indicate a medium gain whereas, those of Teachers 2 and 3, fall in the Low-g bracket. The scatterplot of Figure 5 shows the Gain distribution of participants, per teacher, versus their scores on the Pretest (S_i as a percentage). That of Figure 6 shows the average Gain versus the average pretest score for students, and their teachers, taking either a regular physics course or to an honour's physics course. The slopes of the lines in each scatterplot represent the lower and upper boundaries of the

Medium-g bracket (Hake, 1998). The dots found in the region between the lines belong to the Medium-g bracket, and those on the outside of that region belong to either the Low-g bracket or to the High-g bracket.

Table 5: Average normalized gain per teacher and for all teachers

	Teacher-1	Teacher-2	Teacher-3	Teacher-4	Total
N	48	17	13	95	173
<g>	.384	.241	.243	.388	.362
Std. Deviation	.271	.271	.304	.201	.338

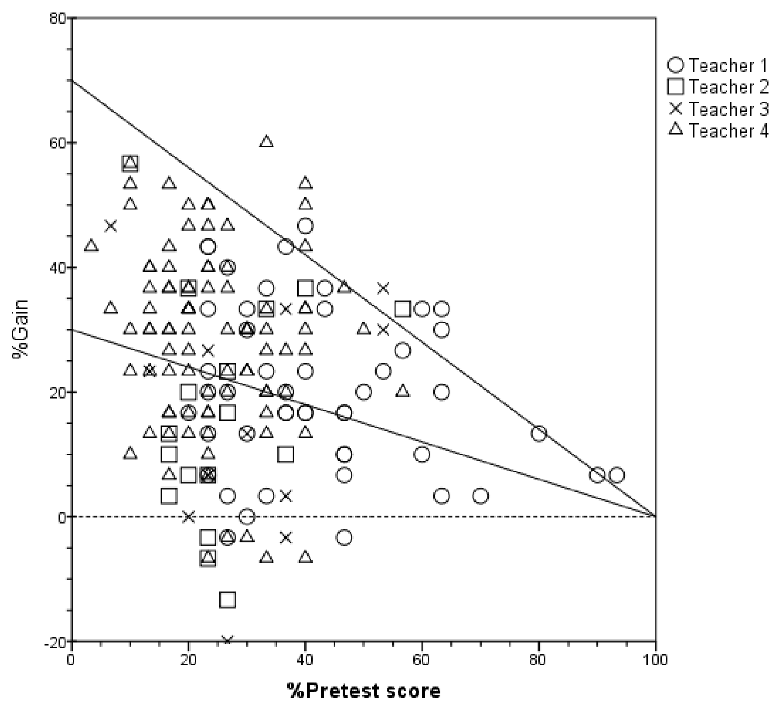


Figure 5: Gain distribution of participants

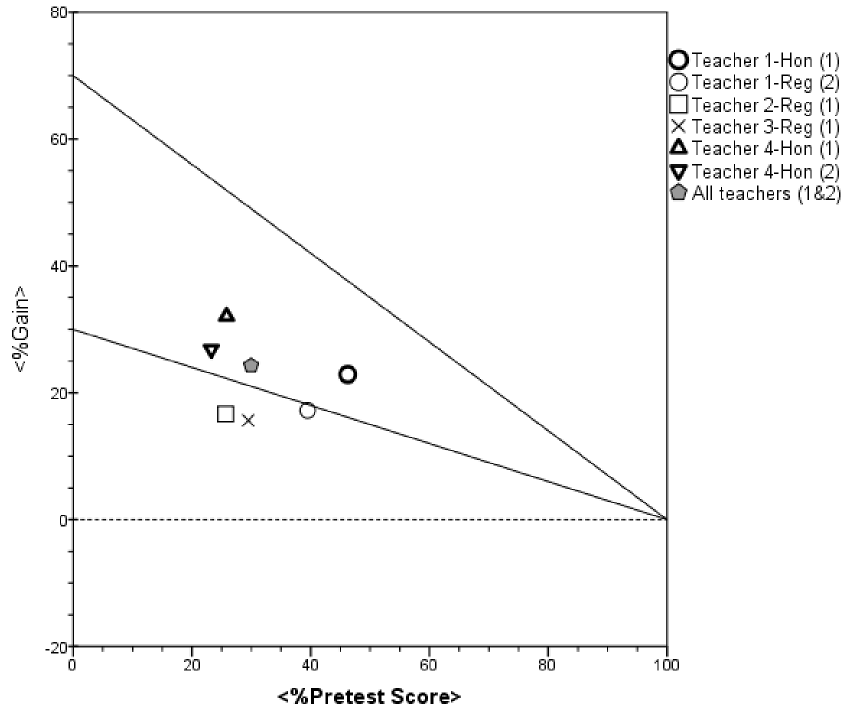


Figure 6: Average gain per course (honors or regular)

The scatterplot of Figure 6 shows that students in advanced classes (bold symbol) perform better with IE methods than regular students. This finding corroborated results found by Hake (1998) and by Hestenes et al (1992). The courses of Teacher 2 and 3 are courses for regular students. Similar scatterplots in Figure 7 and in Figure 8 highlight respectively the distribution of participants and of their averages based on their course grade (1 for weak students and 5 for strong students).

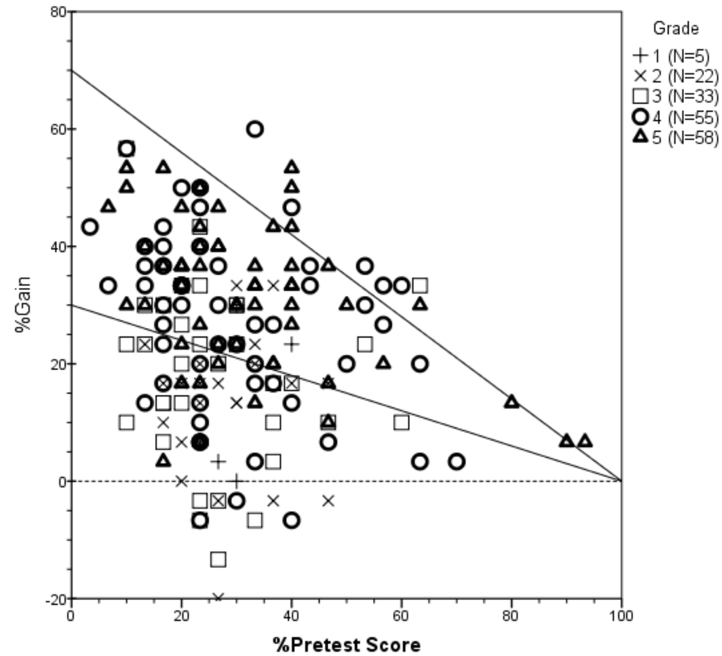


Figure 7: Gain distribution based on course grade

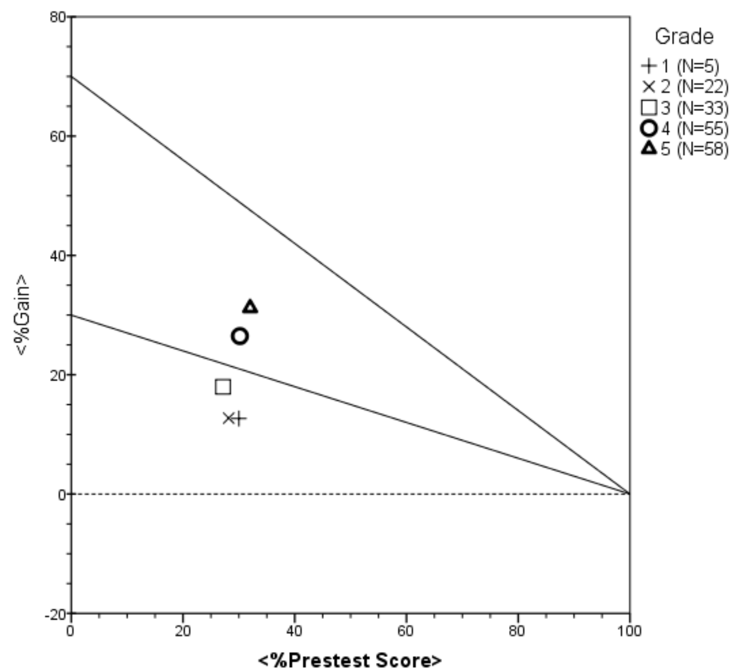


Figure 8: Average gain distribution based on course grade

The symbols in bold, in both figures, are for the strongest students. The scatterplots show that advanced students, regardless of their courses, score higher gains. These results reiterate the conclusion that advanced students benefit more than regular students. To examine this observation with more details, we evaluated the gain achieved by the strongest students taking the regular courses.

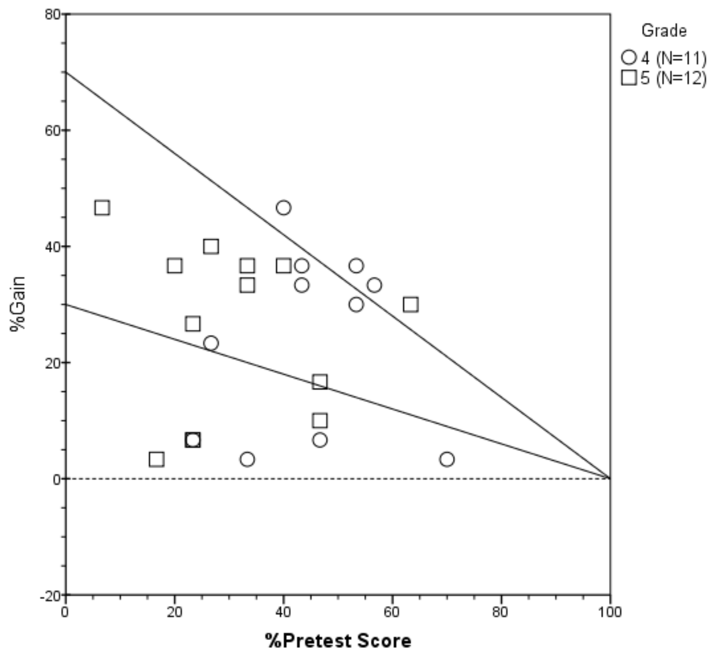


Figure 9: Gain distribution of strong students taking regular courses

The scatterplot in Figure 9 shows the gain distribution of the two strongest categories of students taking regular courses. It shows that their gains range from medium to high. Which indicates that the gain favors the strongest students regardless of their course.

The results from Hake (1998) indicate that the gain of both regular and honor's courses, who followed IE methods, ranged from medium to high. This study partially reflected this result, where only honor's courses showed similar gains. Even though the gain of most top students in the regular courses was above medium, the average gain of all students in those courses was not. For one regular course for Teacher-1, of the 43 enrolled students, only 25 completed both pretest and post-test of the FCI. Two students missed the post-test and 16 missed the pretest. Of the 16 students who only took the post-test, 11 scored 17 or higher (out of 30) and 6 of those scored 25 or higher. Considering the proximity of that group to the threshold of the Medium-g, factoring in the missing values would make the group cross that threshold.

As for the other two regular groups, it is unclear why they fell in the Low-g bracket. One reason could be the small number of students in those groups (N=13 and N=17). Hake (1998), to increase statistical reliability, avoided including groups with less than 20 students in the published scatterplots.

4.1.4 The epistemological test results

In this section, we explore the results from the Disciplined-Focused Epistemological Beliefs Questionnaire (DFEBQ) developed by Hofer (2000). Of the 27 items of the questionnaire, 18 items were used by Hofer to identify four epistemological factors which are: Certainty/Simplicity of Knowledge; Justification for knowing: Personal; Source of Knowing: Authority; and Attainability of Truth. Answers to the items are collected on a 5-point Likert scale ranging from 1 (totally disagree) to 5 (totally agree). For each of the 4 factors, one end of the scale represents the expert view and the other end represents the novice view. Table 6 lists the items for each factor as well as the Novice/Expert view of the corresponding scale. To maintain the same trend of answers for the first factor, the answers to items 11 and 23 were inverted. This change means that, for all items in the first factor (Certainty/Simplicity of Knowledge), more expert-like the answers correspond to lower scores. For each participant, in both pre-test and post-test, we calculated the mean score of all items belonging to the same factor. A paired sample t-test was used to compare the means of pretest and post-test for all four factors. The basic assumption for a paired sample t-tests (null hypothesis-H_0) is that the means are not significantly different.

Table 6: Items per factor of the DFEBQ

			Totally Disagree	5-point Scale			Totally Agree
Factor		Items	1	2	3	4	5
1	Certainty/Simplicity of Knowledge	1, 2, 5, 9, 18, 24	Expert				Novice
		11, 23	Novice				Expert
2	Justification for knowing: Personal	12, 21, 25, 27	Novice				Expert
3	Source of Knowing: Authority	3, 6, 20, 26	Expert				Novice
4	Attainability of Truth	13, 17	Expert				Novice

Of the 210 participants, 67 (31.9%) were excluded from the analysis because their data on this test was incomplete. They partially or completely failed to complete either the pretest or the post-test. All 13 students of Teacher 3 were excluded because their data was incomplete. Table 7 and Table 8 respectively list calculated means and the results from the paired t-test for each factor.

Table 7: DFEBQ mean scores per factor on the pretest (Pr) and Post-test (Po)

		Mean	N	SD	Std. Error Mean
Pair 1	Factor1Pr	2.47	143	.57	.048
	Factor1Po	2.51	143	.72	.061
Pair 2	Factor2Pr	2.94	143	.61	.051
	Factor2Po	2.78	143	.61	.051
Pair 3	Factor3Pr	2.99	143	.64	.053
	Factor3Po	3.01	143	.71	.059
Pair 4	Factor4Pr	3.12	143	.87	.073
	Factor4Po	3.09	143	.93	.078

Table 8: Paired t-Test for each factor of the DFEBQ

	Paired Differences							
			Std. Error	95% Confidence Interval of the Difference				
	Mean	SD	Mean	Lower	Upper	t	df	Sig. (2-tailed)
Certainty/Simplicity of Knowledge	-.04	.54	.04	-.13	.05	-.95	142	.343
Justification for knowing: Personal	.16	.63	.05	.06	.27	3.11	142	.002
Source of Knowing: Authority	-.02	.65	.05	-.13	.09	-.39	142	.700
Attainability of Truth	.03	.88	.07	-.11	.18	.43	142	.670

Results shown in Table 7 indicate that there is no significant change in the means for three of the four factors. A significant change was only observed for the second factor: “Justification for knowing: Personal”. The results from the pre-test ($M = 2.94$, $SD = 0.61$) and post-test ($M = 2.78$, $SD = 0.61$) on this factor indicate a significant change following the study, $t(142)=3.11$, $p=.002$. The change is significant and indicates a decrease in the mean of the post-test with respect to that of the pre-test. A decrease in this factor represents a shift away from the expert view toward the novice view. As mentioned in Section 2.4 the use of the DFEBQ in this study was in part to compare results obtained with high school students to those obtained from university students (Kalman, Sobhanzadeh, Thompson, Ibrahim, & Wang, 2015) who also worked with a combination of Labatorials and RW. Our findings corroborate a part of their findings. Kalman et al. (2015), noted a significant change on factor-1 (Certainty/Simplicity of Knowledge) and on factor-2 (Justification for knowing: Personal). The change they noted on the second factor was also a decrease in the means between the pre-test and the post-test. The difference in their study was that the decrease in the means of the experimental group was less than that of the control group. Further investigation is required to understand the reason for this decrease. Hofer (2000) showed that epistemological beliefs are discipline-based. In the factor analysis she conducted on the results of psychology students and science students, she found that science students hold significantly different beliefs that those held by psychology students. Muis et al. (2014) conducted interviews with students from high school, college and university students to ascertain how they interpreted the items in the DFEBQ. Although they found that students' interpretations of the items approached an acceptable degree, they also found that students interpreted several keywords or items in a manner not intended by the researcher. They also found the interpretation of items was domain-dependent. This finding corroborates that of Hofer (2000) about domain specificity. Royce (as cited in Chen, 2017) proposed that students may evolve specialized domain epistemological beliefs as they progress to higher education. That one would not expect high school students to demonstrate evidence of interactions between domain-specific and general beliefs. High school students' beliefs, which lie in the general domain, may have affected their interpretation of the domain-specific DFEBQ. How the initial knowledge of students affects their interpretation of the text and presented knowledge was discussed through the introduction of RW in Section 2.1. Specialisation seems to be a lens through which students interpret the questions. Since high school students did not yet specialize in a particular topic, their views of epistemology remain unfocused. The study was not designed to address these, domain-specific and domain-general, views of epistemology. The decrease in the means of the second factor might be due to the combination of RW and Labatorials or to other factors such as the instrument used, the age or level of the students, their field of study, or how they interpret the items in the questionnaire.

4.1.5 The concept maps results

Students were asked to complete a concept map (CM) by choosing labelled boxes from a set of 11 and connecting them with labelled arrows known as propositions. The analysis and rating of 85 pairs of CMs are presented in this section. The rating is based on the "relational method with master map" and on the "holistic method with master map" both described in McClure et al. (1999). The first method is based on grading propositions connecting different boxes (or nodes). The second one is an evaluation of the student's general understanding of the relations between the different concepts in the CM. For both methods, raters are guided by a Master Map (MM), which highlights the targeted propositions and general form of the CM.

4.1.5.1 Retained concept maps

Only CMs that exist in pairs of pretest and post-test were retained for this analysis. Single concept maps (for either pretest or post-test) were not retained. Of the 210 participants in this study, only 85 pairs of CMs were retained. All 85 pairs of CMs were provided by teacher 4. Teacher 3, with 13 participants, submitted 4 single CMs. Teacher 2, with 22 participants, submitted 11 singles and 12 pairs of CMs. None of the 12 pairs of CMs was retained because of the evident lack of seriousness detected in the CMs. They either lacked enough concepts (3 or 4 concepts) or propositions. Teacher 1, with 67 participants, provided 64 pre CMs and none of the post CMs. Teacher 4, with 108 participants, provided 100 pairs and 8 single CMs. Of the 100 pairs, 15 were rejected for either lack of seriousness or duplicates (the same concept map was given in both pre and post). Teachers 1, 2 and 3 apologized for not handling this part of the study the way they were supposed to. They mentioned that they were too focused on other aspects of the study and data collection that they either forgot to handle the CMs or they forgot to ask their students to work on them or they could not fit them in their course planning.

4.1.5.2 The Master Map

The Master Map (MM) in Figure 10 represents the model of what is expected of students and it was constructed based on CMs submitted by teachers 1, 2 and 4. Teacher 3 did not submit a CM. The three CMs submitted by teachers were remarkably similar. They particularly had the same main 3-thread structure. Each thread relates a force, under a specific condition, to the relevant acceleration, velocity and trajectory.

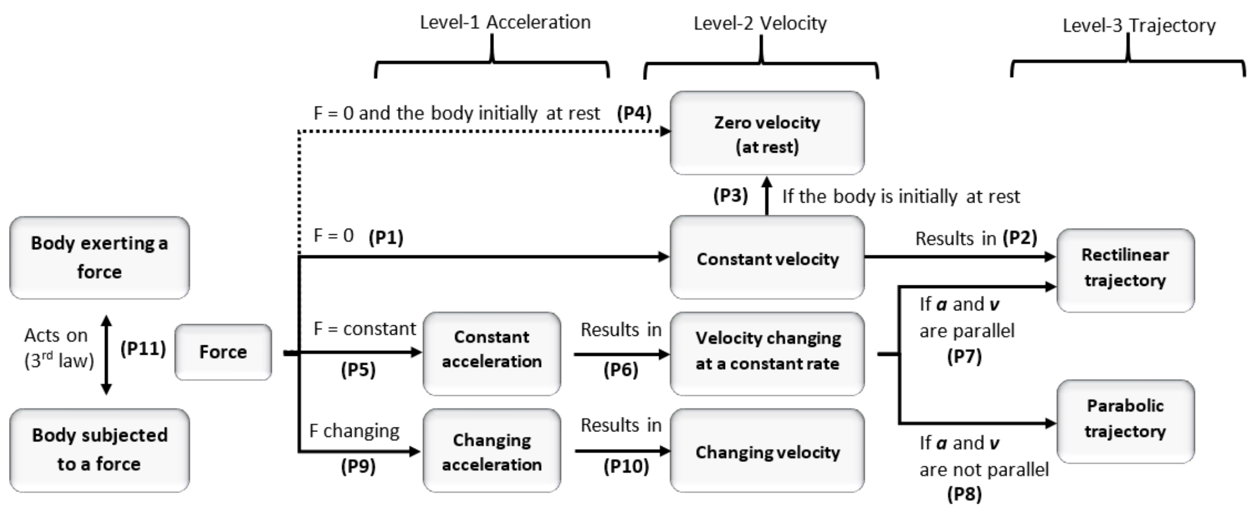


Figure 10: The Master Map

In the first thread of the MM, the force is null (or the sum of forces is null) which leads to a constant velocity (acceleration null), which leads to a rectilinear trajectory. The case of zero velocity (body at rest) is a derivative of this thread line. In the second thread, the force is constant (or the sum of forces is constant) which leads to a constant acceleration, which leads to a velocity constantly changing which may lead to a rectilinear trajectory (if the acceleration and velocity are parallel) or to a parabolic trajectory (if the velocity is not parallel to the acceleration). In the third thread, the force is changing (or the sum of forces is changing) which leads to a changing acceleration, which leads to a changing velocity. In a somewhat separate part of the MM, there is a mention of Newton's third law through the interaction between two bodies.

4.1.5.3 Rating of the Concept Maps

Three raters independently evaluated the CMs. One rater is the researcher and the other two raters are graduate students from the department of physics who completed a Master's in Physics focused on Physics Education Research. CMs were rated following two methods. The first method is the relational with MMand the second method is the holistic with MM (McClure et al., 1999).

The relational method with MM requires the rater to grade proposition in the CM identified by the MM. Each arrow in the MM represents a proposition. As defined by McClure and Bell (1990) a proposition is "two concepts connected by a labeled arrow indicating the relationship between the concepts". There are 11 propositions identified on the MM (labeled P1 to P11). Each proposition is evaluated along a four-point scale ranging from 0 to 3. The evaluation protocol, given in Figure 11, was proposed by McClure et al. (1999, p. 482) and was followed by the raters to rate the CMs.

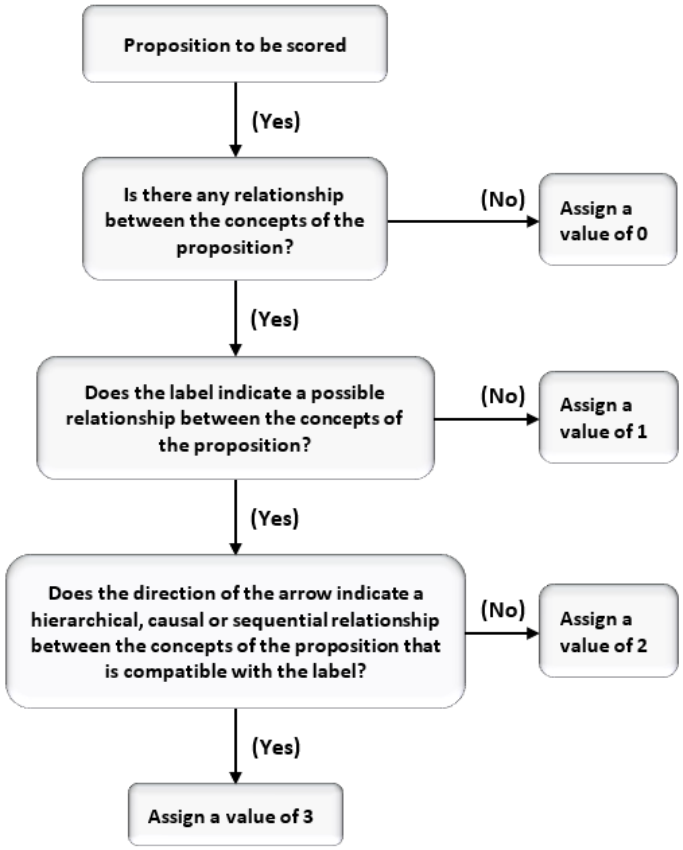


Figure 11: Protocol for the relational scoring method

Table 9: Description of the concepts related by the propositions of the Master Map

Force	←	P1	→	Velocity constant
Velocity constant	←	P2	→	Rectilinear trajectory
Velocity zero	←	P3	→	As a special case of Velocity constant
Force	←	P4	→	Velocity zero
Force	←	P5	→	Acceleration constant / Velocity constantly changing
Acceleration constant	←	P6	→	Velocity constantly changing
Acceleration constant / Velocity constantly changing	←	P7	→	Rectilinear motion
Acceleration constant / Velocity constantly changing	←	P8	→	Parabolic trajectory
Force	←	P9	→	Acceleration changing / Velocity changing
Acceleration changing	←	P10	→	Velocity changing
Body exerting a force	←	P11	→	Body subjected to a force

The fourth proposition (P4) in the MM is represented by a dotted line because it appeared in only one of the three CM presented by the teachers. It is included in the MM as an alternative to the route of the sequence P1-P3 relating the force to a body at rest. Table 9 presents a description of the concepts joined by each proposition of the MM.

Prior to the rating process, several CMs were examined to verify whether the MM can practically be used to evaluate the CMs and their propositions. This examination revealed that the MM was suitable for the evaluation of the CMs. The examined CMs revealed that the students generally followed the same thread pattern of the MM with some differences related to the order of the chosen concepts in a thread. This order is identified by the levels in the MM (shown on the upper part of the MM). For example, a student would start with the force then move to velocity (instead of acceleration, like in the MM), then acceleration, then trajectory. Students also would start with force then to trajectory, then to velocity and finish with acceleration. The order of concepts in a thread was deemed secondary and did not negatively affect the rating of the CM.

When following the relational with the MM method, raters based their evaluation on the MM, on the protocol to score the propositions and on the following guidelines:

1- P3 and P4 cannot be simultaneously marked because this would increase the student's total score. Both propositions reach the same conclusion. If a student offers both possibilities, then only one will be rated to prevent an unnecessary and unfair advantage compared to a student who was content with only one choice.
2- Students are not expected to use exclusively the box labelled force to start their CMs. The other two boxes containing the force are equally accepted. Namely, the box labelled "Body subject to a force" and the box labelled "Body exerting a force".

3- If a student uses the box velocity changing, the rater is required to assume that the student means that the velocity is changing but not at a constant rate because that option is provided.

4- All arrows should be labeled as required in the task description and the provided example. However, if an arrow is not labelled, then the rater would assume that the intended label is either “leads to” or “results in” or “gives” or “can be”.

5- In some cases, arrows are ideally labeled with a numerical expression or with a precise description involving a rigorous use of vector expressions. However, such labels are not mandatory. In most cases, students often would substitute a rigorous description with a simple possibility without needing to go any further. Not necessarily because they don’t know how to proceed but because they did not think that it was required. For example, a student links a constant acceleration with an arrow to rectilinear trajectory and with another arrow to a parabolic trajectory with both arrows labeled “can be”. Meaning that a constant acceleration can be on a rectilinear trajectory or on a parabolic trajectory.

The leniency in the rating offered in points 4 and 5 of the guidelines is justified for two reasons. The first is that unlike other studies involving CMs, students in our study did not receive any training on how to complete a concept map. Their only guide was a paragraph describing what is expected from them and an example of what a concept map looks like. The example does not show arrows with labels having numerical or vector expressions. Raising the bar of expectations would be misplaced in this case, especially with students for whom this is their first physics course. The second reason is that our main goal from using the CMs is to probe the presence of connections between the different concepts and not necessarily the presence of connections perfectly defined. Considering the example given in the last point of the guidelines above, connecting a constant acceleration to either trajectory or to both trajectories is valuable enough to be recognized without having to use formal justifications like those of the MM.

In some cases, the raters had to exercise personal judgement to rate the CM. In these instances, the students did not follow the same thread patterns as that of the MM yet they managed to properly relate the concepts in their map. One example is when students relate the force to a changing velocity, then, as a subcategory, related it to a velocity changing at a constant rate. This situation represents a divergence from the threads in the MM however, the concepts are conveniently related. In such cases, the rater judged which of the connections made by the student correspond to those of the MM even though such connections were not directly evident.

As a second method for rating CMs, the raters provided a global evaluation of the CM known as the holistic method with MM (McClure et al., 1999). Each CM was graded on a scale from 1 to 10. The higher the grade the higher the quality of the connections perceived by the raters and the higher the resemblance of the structure to that of the MM.

A set of metadata was also recorded for each concept map. The set includes:

- The shape of the CM of five possible shapes: linear, circular, tree, hub/spoke or network.
- The total number of concepts used (the students had the choice of not using all the provided concepts).
- The total number of propositions made.
- Whether the force occupies a central or a marginal position.

4.1.5.4 Main results from the concept map

Following the relational with the MM method for rating CM, the propositions in each CM were identified and scored by each of the three raters. The CM score is obtained by adding the 11 scores of the propositions. Even though there are 11 propositions in the MM, P3 and P4 are not simultaneously scored. With a maximum score of 3 per proposition, the maximum total score per CM would be 30 (for the relational with MM method). The score for each CM in both pre and post is obtained by averaging the scores of the three raters identified as R1, R2 and R3. (R1 is the researcher).

To evaluate the internal consistency between raters Cronbach's alpha was calculated for both rating methods. The alpha coefficient for the relational method with MM is .882 and that of the holistic with MM is .816. These high values of alpha suggest a relatively high internal consistency between the raters. Linearity and normality were systematically checked for all the variables involved in the test results in this section.

Table 10: Mean score per rater for the relational with MM method

	R1 Pre	R2 Pre	R3 Pre	R1 Post	R2 Post	R3 Post	Av Pre	Av Post
Mean	11.65	12.21	13.36	16.79	14.87	15.67	12.41	15.78
Std. Deviation	5.51	5.12	4.54	6.02	6.22	5.45	4.62	5.31

Table 10 shows the means of the scores for each rater as well the average of the raters for both pre and post for the relational with the MM method. Rater R1 is the researcher. The means on the post CMs are higher than those of the pre CMs for both raters. To evaluate the significance of this difference in means, for all raters and their averages, a paired sample t-test was applied. The results of this test are listed in Table 11. The results related to the average scores of raters, from the pre-test (M = 12.41, SD = 4.62) and post-test (M =15.78, SD = 5.31), indicate a significant change in their scores following the study, t(84)=5.64, p<.001.

The Pearson correlation coefficient was used to evaluate the association, for the post-test, between the CM score and the course grade and between the CM score and the FCI score. The results reveal an average, yet significant, positive correlation between the CM scores and the course grade (*r* (83)= .389, *p*<.001) and between the CM score and the FCI score(*r* (78)= .406, *p*=.001). This finding indicates that the connections students make between the concepts is significantly related to their performance in the course.

Table 11: Paired t-test results for the relational and MM method

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	R1 Post - R1 Pre	5.14	5.94	.64	3.86	6.42	7.98	84	.000
Pair 2	R2 Post - R2 Pre	2.66	6.84	.74	1.18	4.14	3.58	84	.001
Pair 3	R3 Post - R3 Pre	2.31	5.57	.60	1.10	3.51	3.82	84	.000
Pair 4	Av Post - Av Pre	3.37	5.50	.60	2.18	4.56	5.64	84	.000

Students identified more propositions in the post-test (M=6.90, SD=1.77) than in the pretest (M=6.03, SD=1.79). To compare the average value of propositions in the post-test to those in the pretest, the average score per proposition was calculated by dividing the average score by the average number of propositions. The paired sample t-test administered to evaluate the differences between the mean scores per proposition in the post-test (M= 2.26, SD=0.48) to that in the pretest (M= 1.95, SD=0.51) indicates that the increase due to the study is significant, t(84)=4.74, p<.001.

Similar results were obtained from the holistic with the MM method. Raters graded the 85 pairs of CMs on a scale from 1 to 10. They evaluated the general quality of the connection made when compared to the MM. The scores were converted to a maximum of 30 to facilitate their comparison to those of the relational with the MM method. Table 12 displays the means per rater for both pretest and post-test as well as the raters' averages (AvH) per test. Rater 1 (the researcher) and raters 2 and 3 are the same raters who graded the relational with the MM method.

Table 12: Mean score per rater for the holistic with MM method

	R1 Pre	R2 Pre	R3 Pre	R1 Post	R2 Post	R3 Post	AvH Pre	AvH Post
Mean	12.81	13.73	13.48	17.93	15.88	15.85	13.34	16.55
Std. Deviation	4.97	4.57	4.57	5.26	6.16	5.57	3.81	4.81

Table 13 displays the output of a paired sample t-test administered to evaluate the significance of differences of means for each rater and their average. The results related to the raters' averages, from the pre-test (M = 13.34, SD = 3.81) and post-test (M =16.55, SD = 4.81), shows a significant change following the study, t(84)=6.69, p<.001. In parallel to the relational with MM method, the Pearson correlation coefficient was used for the holistic with MM method to evaluate the association, for the post-test, between the CM score (AvH) and the course grade and between the CM score and the FCI score. Like the first method, results show a significant average positive correlation between the CM scores and the course grade ($r(78)=.390$, $p<.001$) and between the CM score and the FCI score($r(78)=.349$, $p=.002$).

Table 13: Paired t-test results for the holistic and MM method

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	R1 Post - R1 Pre	5.12	5.27	.57	3.98	6.26	8.95	84	.000
Pair 2	R2 Post - R2 Pre	2.15	6.03	.65	.85	3.45	3.29	84	.001
Pair 3	R3 Post - R3 Pre	2.36	5.60	.61	1.16	3.57	3.90	84	.000
Pair 4	AvH Post -AvH Pre	3.21	4.43	.48	2.26	4.17	6.69	84	.000

Pearson correlation coefficient also revealed a very strong association between the raters' average scores on the pre-test (r (78)= .886, p<.001) and on the post-test (r (78)= .909, p<.001) when comparing both evaluation methods used to rate the CMs. This is an interesting result when considering the time required by a rater to evaluate a CM following each of the methods used in this study. The relational method requires more time and attention because the rater evaluates individual propositions and compares them to those in the MM. Raters following the relational method required between two and three minutes per CM whereas the time required by rater per CM for the holistic was between one and two minutes. That the holistic method required less time than the relational (both with MM) is consistent with findings from McClure et al. (1999). Teachers with limited time available, can use the holistic with the MM method and still find comparable results to those found with the relational with the MM.

The preferred shape for a CM, in both pre and post, is Network with 54% followed by Tree with 34%. None of the students used a circular CM. About 70% of those who used a Network in their pre-CM and 55% of those who used Tree, kept their choice of shape for the Post-CM. The results did not reveal an association between the shape of the CM and the score for either of the used rating methods.

4.2 The fan cart experiment

In this section, we cover the results from the part of the interviews when interviewees were asked to analyse the two-way motion of the fan cart. This experiment is the central part of the interviews and the one that took the longest time to complete.

The two-way fan cart motion starts with the fan on and the cart is held at rest by the hand of the student. Then the student pushes the cart in the direction opposite to that of the fan. The cart accelerates in the direction it was pushed. When the hand of the student is no longer in contact with the cart, the cart starts to slow down till it reaches zero velocity, before it accelerates on its way back to the hand of the student. Depending on their answers and interpretation of the motion of the fan cart, students were asked to draw free body diagrams on the cart at:

Point A: when the cart is speeding up when pushed by the hand of the student;

Point B: when the cart is slowing down when the hand of the students is no longer in contact with the cart.

Point C: when the cart reaches its maximum distance from the hand.

Point D: when the cart is on its way back to the student's hand.

This experiment is intended to give a more detailed description of how students view the relation between force and motion and their associated thought processes. The main targets from using the two-way fan cart experiment are a) evaluate students' abilities to draw free body diagrams in general and particularly at the maximum point of the two-way motion of the cart (point C); b) identify whether students adopt a form of the decay model of a force (Section1.2.1) or the Newtonian model. For either model, the interviewer often tried to verify the extent to which the student was holding-on to that model. Drawing free body diagrams may also reveal the underlying assumptions students make when they choose the forces to draw. Students tend to draw forces based on the motion when they should be drawing forces based on interactions. This should be a part of the main ideas taught in preparation for the fan cart experiment.

In addition to the fan cart experiment, the answers to 3 items of the FCI are analyzed. These items target the impetus view of a force. These items are used to probe whether participants, particularly the non-interviewed, view force as impetus.

4.2.1 Interviewed students' analysis of the two-way motion of the fan cart

Of the 12 interviewed students, six students analysed the two-way motion of the fan cart in a manner corresponding to the Newtonian framework. Four students' analysis corresponded to the long decay model, or with balancing forces at point C, but changed to a description corresponding to the Newtonian framework with prompting from the interviewer. The remaining two students would not change their description, during the limited time of the interview, from the long decay model even when prompted by the interviewer. Table 14 offers a summary of how interviewed students responded to the fan cart experiment.

Table 14: Interviewed students' analysis of the fan cart experiment

Student	Analysis of the cart two-way motion	Academic level	Comments
MEM18	Changed to Newtonian	Medium	Recovered from resultant force and motion
MET18	Newtonian	Strong	Very good analysis
FEU28	Did not change	Strong	Adopted the truncated decay model
FES28	Did not change	Weak	Adopted the long decay model
MFJ38	Changed to Newtonian	Weak	Recovered from resultant force and motion
FFL38	Changed to Newtonian	Medium	Recovered from resultant force and motion
FFC48	Changed to Newtonian	Medium	Recovered from the long decay model
FFK48	Newtonian	Strong	Very good analysis and description
MES19	Newtonian	Strong	Very good analysis, vertical toss mentioned
FEV19	Newtonian	Medium	Good Analysis, mentioned the vertical toss
FFS49	Newtonian	Strong	Good analysis, she was a bit anxious
FFD49	Newtonian	Strong	Very good analysis

4.2.1.1 Successful students

When presented with the fan cart experiment and asked to analyse why the cart moves the way it does, six students offered an explanation corresponding to the Newtonian model of the force. One student had this to say:

> MET18-R170: Initially, when you pushed it, you were giving it a larger force then the fan can compensate for, so it was pushed in the left direction, but eventually after the force, after your hand had left contact with the cart, there was no more force acting on it, so it was only the fan pushing in the opposite direction, and friction, so it gradually came into a slow, and at the point where

> it just stopped, and then the fan was exerting a force on the air, I mean making the air spin, anyways, so it was exerting a force, and it made the cart go back in the right direction.

He was asked to draw free body diagrams at points A, B and C and he completed all three without a mistake. Another student wanted to draw her explanation of the motion of the cart. The drawings were mainly making sketches, not free body diagrams. It is as if she needed to scribble to visualize her thoughts. Her answer gave the interviewer the impression that she adopted the long decay model of the force. The interviewer probed what she meant in this extract from their conversation (Q is the interviewer; S is the student):

> FEV19-R178: When you push it, it goes in that direction until the fan starts to move it that way [she pointed the opposite direction]. You push it and you apply a force on it, and then the force will keep going, like inertia (this is when the interviewer suspected the long decay model), but like, then another force is applied which is the fan and that brings it in the other direction and then there is friction which we have to take into account and the air resistance.
>
> Q: Ok, but when you said now, we have a fan which applies a force, I mean wasn't that force applied when you pushed it?
>
> S: Yeah but the force from when you pushed it, like, you applied a force when you pushed it but it's getting overridden by the fan.
>
> Q: Can you please draw a free body diagram when that cart was pushed with the hand (diagram 1 in Figure 12)?

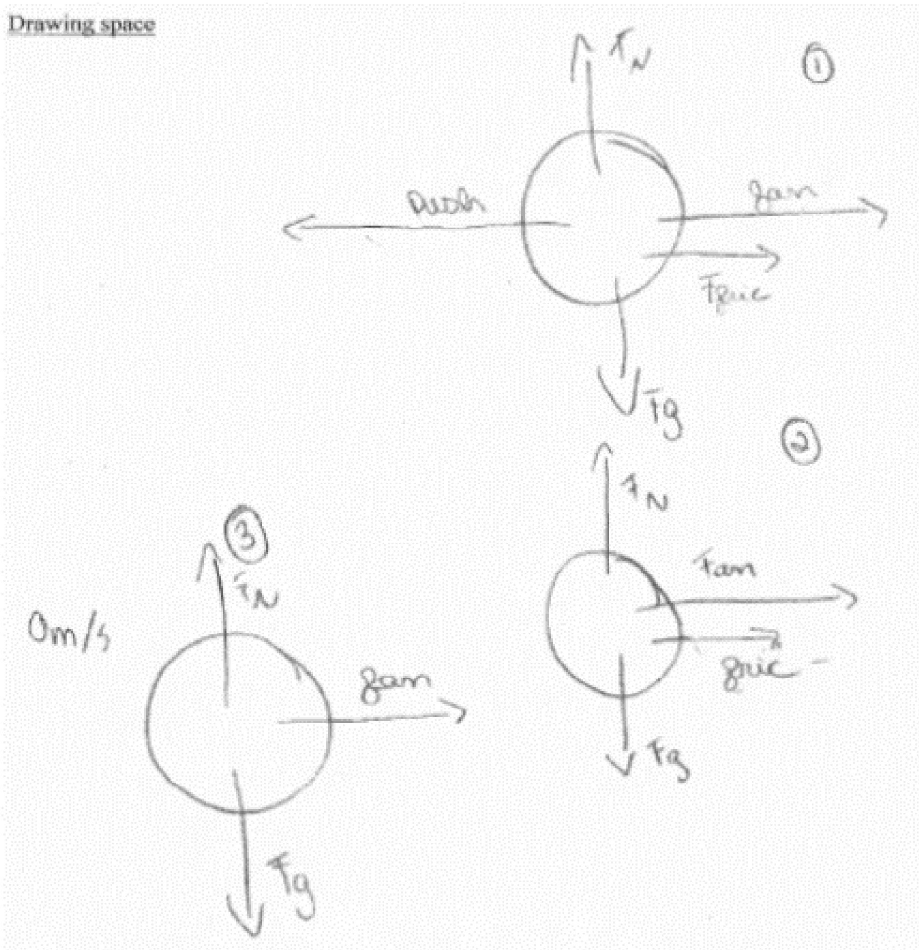


Figure 12: Free body diagrams of student FEV19-R178

Q: can you draw a free body diagram of the cart when it is no longer in contact with your hand somewhere between the maximum point and after the cart left your hand (diagram 2 in Figure 12)? You did not put the force exerted by the hand on the cart?

S: Yes, because it is no longer in contact with the cart.

Q: Let’s say now that the cart has reached its maximum point, can you please draw a free body diagram when it is at the maximum point?

Would it be still at this point?

Q: [while showing the motion of the cart] At some point the cart reaches its maximum distance, can you draw a free body diagram when it reaches its maximum (diagram 3 in Figure 12)?

S: Wouldn't it just look like this (the interviewee points at the second diagram), except for the friction, maybe when its starts going in the other way then the friction would be in the other direction.

Q: So, you are saying it's like the second diagram only without the friction?

Yeah, the friction would be there somewhere it depends on which way it was going.

Q: Ok, can you please draw it.

S: Yeah, but is it still? The fan is still working right.

Q: [while operating the fan cart] Well Is the fan still working?

S: Yeah. Ok, but I'm not sure about the friction because I don't know which way it's going.

Q: So, what is the velocity of the cart at this point, when it's at the maximum?

S: I would say it's zero because it's turning back in the other direction.

In her interpretation of the motion, she evidently removed the force of the hand when there was no more contact with the cart. She was even meticulous about the direction of the friction force at the maximum point. In the last part of the analysis she highlighted the resemblance of the motion of the cart to that of a vertical toss.

The most rigorous explanation of the motion of the cart was given by a student with whom this section of the interview took the shortest time of all interviewees. As an explanation of the motion of the cart she said:

> FFK48-176: When you push it, you accelerate it, you give it an acceleration, but the moment your hand stops pushing, it starts to decelerate, uniformly forward, then it goes, then at some point the speed will be like zero, but the acceleration is still constant, because it's going to go the other way, so it's like positive, negative because it's going the other way.

She also seamlessly completed the force diagrams. When asked why the cart decelerates, she answered because of friction and the force of the fan. This same student complained that her teammates in the Labatorial groups were over analysing simple situations. It is worth noting that she is strong academically.

4.2.1.2 Students who recovered when prompted

The interview with one student (MEM18-169) showed that he struggled to determine the compatibility of the forces and motion at point C (the maximum point). His responses reveal that he was trying to reconcile between a body having a velocity of zero and the sum of forces not being zero. His thought pattern shows that he is starting with the idea that when the velocity is zero then the sum of forces must be zero. He recognizes the presence of the force of the fan and is looking for another force to balance it at point C. The only other force he could find was the force of the hand. Only he was not sure that this would help him because the hand is no longer in contact with the cart. He then tries to use the forces of friction to balance that of the fan. When that did not work, he removes the force of the fan only to put it back again when he considers that the fan is still on at point C. He appears to reach some resolve after this intervention from the interviewer:

> MEM18-169: …but at this point, there is no force exerted by it (talking about the force of the fan), it is equal to something that… I don't know how to describe.
>
> Q: I understand, let me ask you something, as if you are trying to make the forces balance at the peak, right?
>
> S: Yes
>
> Q: My question to you, had they been balanced would it move back?
>
> S: No, it won't. And this is what I'm asking myself, I'm confusing myself.
>
> Q: Ok so why did it stop.
>
> S: It didn't stop.
>
> Q: But at that point you said that the velocity was zero.
>
> S: Yes, at that point it was zero but the whole motion didn't stop.

MEM18 is an example of a student who bases the forces of a free body diagram on motion instead of interactions. This idea that when the velocity is zero, then the sum of forces must be zero is tenacious enough to make him remove the force of the fan just to satisfy it. He clearly has some recollection of the discussions that occurred during the Labatorials, which justifies his last quote. He even expressed his recollection of the fan cart, as soon as the interviewer placed it on the table in front of him. MEM18 even opened his analysis of its motion by saying:" Just a comment, this is one of the things that blew my mind, one of the things that help my pre-understanding crash down and rebuild again".

It’s important to mention that the key question asked by the interviewer would probably not have worked with a student adopting the long decay model of a force. In that model, the force of the hand would be continuously present and diminishing when the hand is no longer in contact with the cart. At point C, the diminishing force of the hand would have reached a value equal to that of the force of the fan thus causing a zero velocity. If a student with this view was asked if the cart would go back when the sum of forces is null at point C, the student would likely answer yes. The justification would be that since the force of the and is diminishing, after point C its value would be less than that of the fan which would drive the cart back toward the hand.

Another student (FFL38-174) had a similar difficulty. She also wants the resultant force to be zero at the maximum point. In order to balance the force of the fan, she drew the force of the hand on the cart after there was no more contact between the hand and the cart. She labeled it as a force at a distance exerted by the hand. When asked if hands could exert forces at a distance, she considered it as the force of inertia. Then she removed this force when conceding that inertia is not a force and that it should not be represented with an arrow-like forces. When asked what the resultant force would look like, she was disappointed to see it opposite to the direction of motion. When asked how the cart would move if the resultant force was oriented like the motion, she then realized that the cart would keep going in the same direction. She was then asked to draw a free body diagram of the cart at point C which she completed successfully. She then noted that at that point the cart is in equilibrium but not at rest. It seems that she recalled this part from the course work.

Regarding Inertia, it is expected that students use it to justify why motion occurs in a given direction when there are no forces (or a resultant force) in that direction. This is how

Newton's first law is introduced in high school; the body keeps moving because of its Inertia which is identified as the tendency of a body to maintain its state of rest or of motion. However, students are not expected to confuse Inertia with a force, such as referring to the "force of inertia", nor represent it as a vector in a free body diagram.

One of the students (FFC48-175) changed to a description corresponding to the Newtonian framework, with hesitation, from the long decay model. The probes and questions of the interviewer helped her focus her attention on the choice of forces. This is her analysis of the motion of the cart and the conversation that followed:

> The strength of your hand when it pushes the cart gives it a certain force, in Newtons, which will make it move forward, but the more it advances, its acceleration will decrease, the force given by your hand will decrease, and then it comes back, it is the force of the fan which pushes, which pushes…
>
> Q: The air
>
> S: Yes, the air
>
> Q: You were going to say wind?
>
> S: Yes, (laughing) that's what I was going to say. The air pushing on this side will make it flip direction while accelerating.
>
> Q: Ok, ok, I now ask you to draw a force diagram of the cart, from the moment my hand no longer touches it until it reaches its maximum point. Choose a time between these two and draw a force diagram of the cart.
>
> [The force of the hand was initially drawn on the body and the force of the fan was not drawn]

Q: What is this force? [pointing at the force of the hand, labeled as a contact force]

S: It's the force of the hand, it comes from the hand.

Q: Is this the force that the hand exerts on the body?

S: Yes

Q: Did you say it's a contact force?

S: Yes, but now it's basically, I'm not sure that there is still the force of the hand.

Q: I repeat, from the moment you let go of it until the moment when it is at its maximum point, this is the phase that you are asked to consider.

S: Yes [the student hesitates]

Q: Are you saying that the force of the hand is still on the body even after letting it go?

S: No, that's what I wrote, but I don't mean that.

Q: But you can change if you want. Because you put it is a contact force.

S: Yes, it would be more of a force at a distance, but I'm not sure it is still there. But is the force of the hand exerted at a distance?

Q: Does a hand exert force from a distance?

S: No

Q: Do you know what happens if the hands exerted forces from a distance?

S: Yes, it would not be good [laughing].

Q: Is there a force, a residue of the force of the hand?

S: No, there is a residue from the force of the hand, but it is no longer applied.

Q: Is it called force?

S: No

Q: Ok, you said no it's not called force?

S: No, I do not think so.

Q: Okay, I called it residue, it's like there is something left here, but is it called a force?

S: No, I don’t think so.

Q: Maybe effect?

S: Yes

Q: But is it called a force?

S: No

Q: Is the fan pushing the body?

S: It pushes it to this side.

Q: But did you draw this force?

S: No

Q: You didn't draw it, but is there a force from the fan on the cart?

S: Yes

Q: So, you must add it (The student adds here the force of the fan), you still put it in the same direction as the friction force. And the force of the hand, do you keep? Do you take it off?

S: No, I'm going to remove it (the student erases the force of the hand).

Q: Why are you taking it off?

S: Because in this phase it is no longer applied on it, it is inertia, but…

Q: It's inertia, you can call it inertia

S: But I can't put it on, but...

Q: What is inertia in this case?

S: The body tends to continue the motion it had at the beginning when the hand pushed the cart, it started to go on this side and even if there is no more force of the hand directly on it, it's going to continue its motion until it equalizes with the fan.

Q: What equalizes with the fan?

S: Basically, as it goes to this side, so to my left, the force of the hand is decreasing, and the force of the fan is increasing.

Q: Okay, now you said the force of the hand is decreasing?

S: Yes

Q: But does this force exist?

S: Yes, but…

Q: You just removed it, but you say that the force of the hand will decrease, so it's still there?

S: The effect of force will decrease

Q: The effect of force will decrease, ok, but not the force?

S: No

Q: Ok, can you draw a force diagram of the body when it is at its maximum point, at the farthest point? [the student draws it correctly].

Q: Why did you put the force of the fan?

S: Because it is exerting a force on it.

Q: Can you draw a force diagram when it's on its way back. [The student draws it correctly].

S: That's it.

Q: Thank you.

The conversation with this student reveals that the course and the activities in the Labatorials helped her decide on the choice of forces. She steered away from the long decay model towards the adoption of inertia as a force. However, she did not start with inertia, which could mean that how she views the concepts and their relations lack clarity. It is uncertain how she would answer if the same analysis is required from her after some time.

4.2.1.3 Students who did not recover

The explanation of two students participating in the fan cart experiment revealed that they adopted the long decay model of the force. Even when prompted and their answers probed by the interviewer their adoption of the model was resilient. The first student is academically strong.

FEU28-R171: Basically there's a force acting this way, there are two forces that are acting against each other, and then the moment, when I push, that's one of the forces and it's greater than the force acted by the fan, so it obviously goes in the direction of the force that is applied in, but then once I let go of the force, the net force becomes only the force of the fan, yeah, so at some point, although my force is still reacted on the body, at some point it will kind of, not diminish, kind of, goes away I guess, and at some point it will stop, and then the only force is the fan.

Q: Okay and why does it come back?

S: Because the fan, of the force of the fan is going this way.

Q: Okay very well, consider this phase, I push the cart, and the cart is no longer in contact with my hand, and this is the maximum point it reached, can you please draw a free body diagram (diagram 1 of Figure 13, the looped arrow indicates the two-way motion of the cart) of the cart, when it's no longer in contact with my hand but before it reached its maximum point?

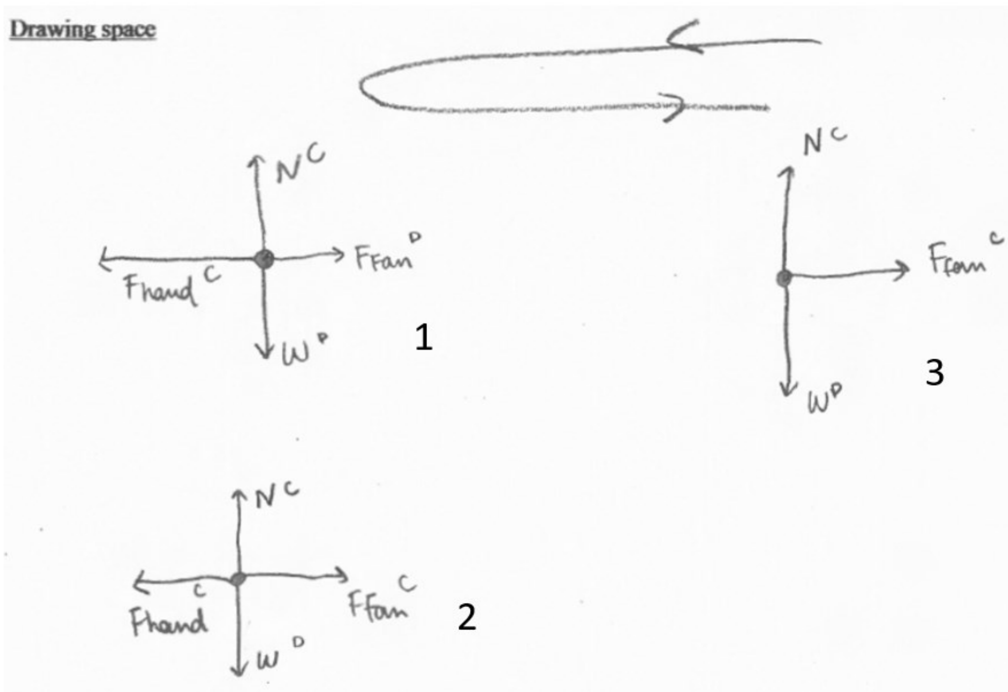


Figure 13: Force diagrams of student FEU28.

Q: So, you said that the normal force, what is that? Is that a “d”?

S: No, no, sorry this is a “c” because the table is acting on the cart.

Q: Very good, so this is the force of the hand and this is the force of the fan. You say here that the force of the fan is a force at a distance?

S: Yeah, I'm sorry I just need to think a little bit

Q: It's not graded you know.

S: Yeah, yeah, I think that it's….

Q: What's troubling you?

S: Cause I'm not sure, because the fan is obviously attached to the body, but the force of the fan is created when it's turning like this.

Q: Do you know why when the fan is on, the cart moves?

S: Okay, yeah, because it's attached, so it's a contact.

Q: You can keep it as it is, but I think it's more contact than a distance. What about the force of the hand, you said that it's a contact force?

S: Yeah but you've let go of it.

Q: Yes, my hand is no longer touching the cart, would there still be a force of the hand exerted on the cart?

S: The force is still here but it just, it gets countered by this force, at the beginning before it reaches the endpoint, the force of the hand is still greater than the force of the fan.

Q: Very well, but you're saying that it's a contact force. Would we put a force on a body if there's no contact?

S: No

Q: But you did put it?

S: Yeah, I'm still thinking. No, I think its distance, because it's still acting on it, but not in contact with it.

Q: But is it a contact force or a force from a distance?

S: Like at the beginning, if we were to draw it in a few steps, right here, if it was at this step [the beginning] it would be a contact, but here it becomes a distance.

Q: You mean a force at a distance?

Yeah

Q: So, the hand exerts a force on the cart at a distance? [The student laughs] why is it funny?

S: Because it’s confusing me a little bit.

Q: So, do we put a contact force there?

S: Yes, I’m going to keep it a contact.

Q: Ok, let us say it reached its maximum point. Can you draw a free body diagram (diagram 2, of Figure 13) at its maximum point? [the student does not draw any of the horizontal forces of the fan nor of the hand]

Q: You didn't draw any horizontal forces here.

S: Yeah because it’s… oh wait, no wait…

Q: So, at the end, there is no force exerted by the fan on the cart?

S: There is, but it’s the same as the hand so these become equal [the student adds two equal and opposite horizontal forces to diagram 2].

Q: So here, they're equal [pointing at diagram 2] but not here [pointing at diagram 1]. Here, [diagram 1] the force of the hand is greater and that's why it moves forward. Ok, why does it come back?

S: Because this becomes greater than the force of the hand. Usually there's something called inertia, there's another external Force which means that it cannot stay in inertia and that's why it goes back this way, yeah. Because you applied the force, usually there's an inertia but there's another force countering it, that means the force can’t stay the same, the motion can’t stay the same.

Q: Ok, I understand, but when it comes to forces you drew, why does it come back?

S: Because the fan’s force is bigger than the hand’s force.

Q: Ok, can you please draw a free body diagram (diagram 3 of Figure 13) on its way back?

Q: And what about the force of the hand?

S: I don't think it's there anymore.

Q: So, at the end it becomes 0?

S: Yeah.

Q: And there is no more force going back. Alright.

The answers given by FEU28 reflect what is known as the truncated decay model of the force. (See Lattery (2016) which was presented in Section 1.2.1.2) Even though she manifested hesitation as certain points of her answers, she nonetheless maintained her argument that the force of the hand persists at a distance and balances that of the fan at the maximum point. She mentioned inertia, however, it was not employed in the analysis of the motion. It seems that her focus was on having balanced forces at the maximum point and other details were sacrificed for that end. This is made more evident in the way she treated the return trip of the cart. In that phase, she completely removed the force of the hand because its presence no longer serves a purpose, despite her analysis that it gradually decreases. This gradual decrease is completely overlooked by her on the return trip of the cart, possibly because the force of the fan is enough to justify the motion of the cart during the return trip. This sudden disappearance of the force of the hand is not to be generalised over all students holding the long decay model of the force. Many students encountered during the discussions of the Labatorials activities maintained the gradual decrease of the force of the hand during the return trip.

The second student (FES28-R171) showed less coherence in her analysis of the motion of the fan cart. She is not strong academically. Here answers clearly show that she adopted, as she was analysing the motion of the cart, the long decay model of the force.

> S: So the propeller is on, when you give it an external push, to the opposite that it would move, to the force of the air, the fan, it will accelerate, and then there will be a change in its inertia, it will eventually get to a velocity like zero, and then it will start going in the opposite direction that it was initially going. Because eventually, the force that you gave it wears off I guess, you could say so. As I said the velocity will get the zero, and then the force of the fan will cause it to move back, and this is also a part of air resistance.
>
> Q: When you said that the inertia decreases, what do you mean the inertia decreases?
>
> S: No there's a change in inertia.
>
> Q: You said the inertia changes.
>
> S: Yeah, so it's initially moving, and then, like, if an object is moving, it's going to stay like that, unless there's an external force applied on it, and in this case, it would be I guess the propeller. Because it's causing like, air resistance against the way that the cart is moving, so it'll eventually like come to a stop.

Q: Can you draw a free body diagram of the cart from the moment it left my hand, so it's no longer in contact with my hand, after I pushed it, and before it reached its maximum point. Somewhere here, can you please draw a free body diagram of the cart after it was pushed and before it reached its maximum point (diagram 1 of Figure 14, the looped arrow indicates the two-way motion of the cart).

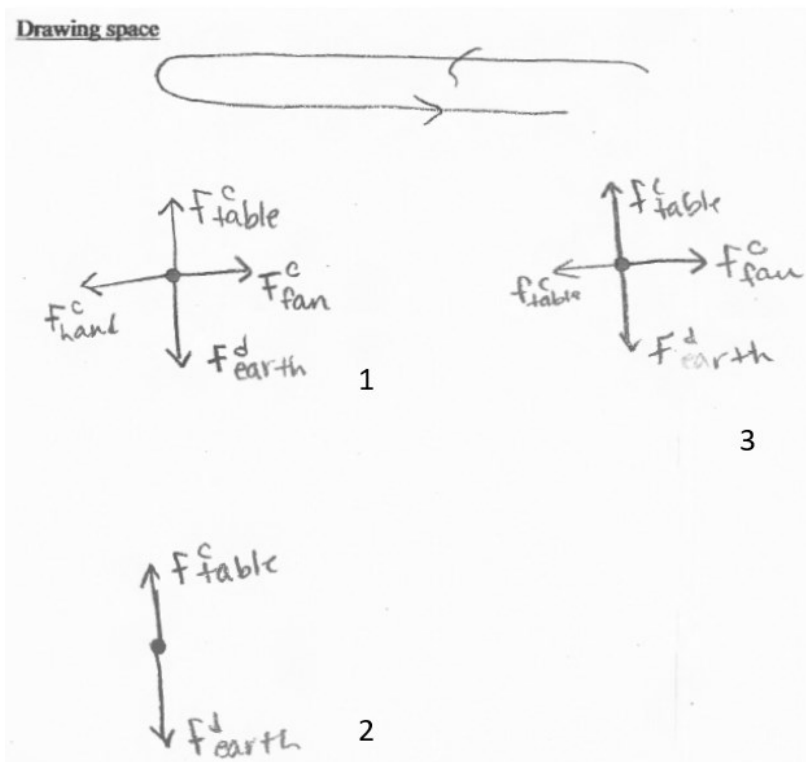


Figure 14: Force diagrams of students FES28

Q: You drew the force of the hand on the cart, and what is the “C”?

C: Contact

Q: So, this is a contact force?

S: Your hand was on it.

Q: Yes, but we said that it was after the contact.

S: I don't know what is the force. I would assume… I don't know.

Q: You are saying it's a contact force, but I don't see any contact. Is there a force exerted by the hand on the cart in this case?

S: No, but it's moving.

Q: It's moving that way, you are right, it is moving that way. What if I ask you to draw a free body diagram of the cart when it's at the maximum point (diagram 2 of Figure 14).

S: I'm going to assume it stopped, I don't think there is like a …. but the fan is on, but it like it comes to a stop, so I don't know.

Q: You are saying that it comes to a stop, does it stop completely?

S: Yeah, at some point, even though it's for a bit of time, it doesn't like full stop for like five seconds, but stops for like, I think yeah.

Q: But as you said the fan is still on.

S: Yeah, so I don't know.

Q: But is there a force exerted by the fan on the cart.

S: Yeah.

Q: But you didn't draw that.

S: Because it's not moving.

Q: Ok, let's say it's going back. Can you draw a free body diagram (diagram 3 of Figure 14) on its way back?

S: I think there is friction also here, but I don't know.

Q: You can put it if you like. In this case [pointing at diagram 1], why would it slow down?

S: Because the force of the fan is making it move in the opposite direction.

Q: Yeah, but you drew the force of the hand too.

S: Yeah

Q: But if the force of the hand is pushing it that way, and the fan is pushing it the opposite way, why would it slow down?

S: Oh, Oh, I know why, because the force of the propeller becomes larger than the force like you gave to the cart, like you initially did.

Q: Alright, thank you.

This student seemed to interpret a contact force as one where the contact occurred, not necessarily in the present. She labeled the force of the hand on the cart as a contact force because the hand was in contact with the cart yet not at the moment represented by the free body diagram. Like the first student, she mentions inertia but does not use it in the justification of motion. Also, like the first student, she seems to be focused on balancing forces at the maximum point, only she achieved that goal differently than the first student. Instead of balancing the force of the hand with the force of the fan at the maximum point, she removed both forces, while justifying that with the argument that the body is not moving. Her analysis of the motion of the cart reveals inconsistencies even in her adoption of the long decay model.

Both students' approaches to the analysis of the fan cart motion and of drawing free body diagrams indicate that they consider motion as the main indicator of forces and not interactions.

4.2.2 The FCI items

The interviews provided a relatively detailed view of how students analyse demanding situations. However, the number of interviewees is relatively small with respect to the number of participants. In order to form an image of how participants evaluate similar situations to those targeted in the interviews, we analysed items 13, 18 and 30 of the FCI presenting such situations. Each of these items tackles the forces exerted on a body put in motion. The correct answer to each of those items represent the Newtonian view of a force. Among the wrong choices for those items, are choices related to the force as impetus which in turn could be related to particularly the long decay model or the truncated decay model. The choices, made by participants, in both pretest and post-test, are indications of which model of the force they adopted.

4.2.2.1 Item 13: a vertical toss

Item 13 describes a vertical toss of a steel ball by a boy. Respondents are required to consider the motion of the ball during the interval which starts after the ball left the boy's hand and ends when the ball touches the ground. The two-way motion of the fan cart models the motion of the ball described in this item. Each of the five choices of answers describe the force or forces exerted on the ball during the required interval. Option 4 of the provided choices represents the correct-Newtonian interpretation of the situation. Options 2 and 3 include descriptions of the force what about the other decay model.

Table 15: Cross-tabulation of answer choices of item 13 of the FCI

		Item 13 Pre				Total
		1	2	3	4	
Item13 Post	1	1	2	2	1	6
	2	2	15	11	0	28
	3	5	14	24	2	45
	4	7	35	41	11	94
Total		15	66	78	14	173

Table 15 shows a cross-tabulation of item 13 between the choices made by participants in the post-test with respect to those made in the pretest. The results in Table 15 show that on the pretest, 144 students (83.2%) of a total of 173 students chose either option 2 (66) or option 3 (78). Only 14 students chose option 4, which is the correct choice. The results clearly indicate that, prior to the study, students had predominantly adopted the impetus model of the force. Whereas in the post-test, a clear shift toward the Newtonian model is observed. The number of students who chose option 4 increased from 14 in the pretest to 94 in the post-test. Of those 94 students, 35 had chosen option 2, and 41 had chosen option 3 of the pretest.

4.2.2.2 Item 18: Boy swinging on a rope

Item 18 describes a boy swinging on a rope. The forces exerted on the boy are considered at a point during the swing, lower than the highest point. Each of the choices provided as answers lists several forces. Option 2 is the correct-Newtonian choice and options 3, 4 and 5 include forces related to the Impetus.

Table 16: Cross-tabulation of answer choices of item 18 of the FCI

		Item 18 Pre					
		1	2	3	4	5	Total
Item18 Post	1	0	0	1	0	10	11
	2	2	17	17	20	48	104
	3	1	0	2	3	2	8
	4	1	4	6	7	9	27
	5	1	0	6	5	11	23
Total		5	21	32	35	80	173

The cross-tabulation of this item between the options of the post-test in contrast to those of the pretest are presented in Table 16. The results of the cross-tabulation indicate a shift in the students' choice from options 3, 4 and 5 of the pre-test toward option 2 of the post-test representing the Newtonian view. The number of students who adopted the Newtonian view increased from 21 in the pretest, to 104 in the post-test. Of those 104 students, 85 had chosen either option 3, 4 or 5 of the pre-test.

4.2.2.3 Item 30: Tennis ball hit with a racquet

In item 30, a tennis ball is hit by a racquet. Students are asked to identify the forces exerted on the ball after it was hit and before it touches the ground. One of those forces is the force of the hit. Option 3 of the answers is the correct-Newtonian choice and options 2, 4 and 5 include the force of the hit which is related to the Impetus. The cross-tabulation of the choices of this item presented in table 10 indicates that the preferred choice shifted from option 5 in the pretest to option 3 in the post-test

Table 17: Cross-tabulation of answer choices of item 30 of the FCI

		Item 30 Pre					
		1	2	3	4	5	Total
Item 30 Post	1	0	0	0	0	2	2
	2	1	1	0	0	0	2
	3	0	6	11	2	77	96
	4	0	0	0	1	2	3
	5	0	9	4	4	53	70
Total		1	16	15	7	134	173

Option 3, the correct choice, recorded an increase in the number of students from 15 students in the pretest to 96 students in the post-test

4.2.2.4 Correlations between the items' scores

To assess the consistency of students in choosing the correct Newtonian model of the force, we evaluated the correlation between the scores of items 13, 18 and 30 for both the pretest and the post-test. The normalized gain is also included in the analysis to evaluate the relation between the scores on these items and the total score. Table 18 shows the Pearson correlation coefficient between the selected items and the normalized gain of the FCI.

Table 18: Correlation of items 13, 18, 30 and Normalized Gain (N. Gain) of the FCI

Items	13 Pre	18 Pre	30 Pre	13 Post	18 Post	30 Post	N. Gain
13 Pre	1						
18 Pre	.214**	1					
30 Pre	.285**	.263**	1				
13 Post	.144	.092	.035	1			
18 Post	.112	.158*	.209**	.343**	1		
30 Post	.098	.052	.114	.499**	.258**	1	
N. Gain	.150*	.057	.037	.665**	.460**	.550**	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Results of the Pearson correlation indicated that there was a significant positive association between the scores, on the post-test, of the 3 items as well as between each of those items and the normalized gain (0.21<= r (171) <= .67, $p < .01$). These significant correlations are highlighted in gray in Table 18. This finding suggests that students who identify the right answer on any of the 3 items are more likely to identify the right answer on the other items and obtain a high normalized gain. It is thus unlikely that a student accidentally obtained the right choice on one of the items in the post-test. These results indicate that students reached a consistent degree of adoption of the Newtonian model that manifests itself across the items which evaluate it.

This finding is particularly important for our study which is designed to help students adopt Newtonian ideas about forces, namely the role of the agent (the body exerting the force) which highlights the force as a property of an interaction between bodies and not that of the body. It also shows that the shift toward Newtonian ideas, observed with the interviewed students, seems to extend to most participants. This is most reassuring for us because it corroborates findings from the interviews, thus adding to their representational value, and adds to other results that our approach to teaching dynamics yields the desired results.

4.2.3 Two-way motion of the cart as an introduction to free fall

The two-way motion of the fan cart is intended as an introduction or as support activity to free-fall, particularly, the vertical toss. One of the reasons for which we used the fan cart is the similarities its two-way motion offers to the vertical toss. The related results gathered, from students and teachers, are discussed in this section. In the following chapter, a section is dedicated to the observations of this experiment.

Teachers valued the transition from the two-way motion of the fan cart to the vertical toss. While Teachers 1 and 2 completed projectile motion as a part of kinematics which is covered before dynamics, Teachers 3 and 4 completed the projectile motion after covering dynamics.

Teachers 1 and 2 shared that when their students initially completed the activity then moved to the vertical toss activity, they were not aware of the connections between the two. For some students, it was when they draw the force diagrams that they noticed the resemblance of the two activities, whereas for others, it was after they had completed the force diagrams. According to them, this was one of the most enjoyable moments of the course; the moment, during the Labatorial activity, when their students saw the connection between the two-way motion and the vertical toss. Students were repeating: “it’s the same thing only horizontal”. As one of the interviewed student (MEM18) expressed: “this is one of the things that blew my mind, one of the things that help my pre-understanding crash down and rebuild again”. Two other interviewed students recalled the two-way motion of the fan cart as the one resembling free fall.

Teachers 3 and 4 noted a seamless transition between the two-way motion of the fan cart and the vertical toss. They recalled spending significant time, with their groups during Labatorials, on the two-way motion of the cart. But they spent hardly any time with their students on the vertical toss. Teacher 4 noted: “students seemed to know what to do and how to do it”. Even when teachers wanted to intervene to see how things are going with teams during the work, the students would wave them off, citing that help is not needed. Teacher 3 and 4 also reported that, while completing the projectile motion following dynamics, they did not register any conceptual difficulty, only difficulties related to the calculations involved in the analysis of this motion. Teacher 4 added that he had never seen this degree of conviction in his students when it comes to the “how” and “why” of projectile motion. Thus, he considered the transition from the two-way motion to the projectile motion ideal from a conceptual standpoint.

The impact of the two way-motion of the fan cart was in all the discussions with the teachers during the study. All teachers expressed their appreciation of this activity and for the connection it creates to the vertical toss, particularly the analysis of forces and motion at the maximum point. The analysis of forces and motion at that point is one of the most challenging situations for high school students to tackle and for their teachers to manage. Teachers mentioned that they had a lot of “fun” discussing this activity with their students. Teacher 3 noted that every detail discussed with the students during this activity brought at least one of them to make a connection they had not made before. They also valued how it brought back and integrated the concepts of kinematics in the analysis of the situations presented. While teachers complained that Labatorials took more time than estimated, none of them complained about the time dedicated for Labatorial 5 and to the two-way experiment of the fan cart.

Chapter 5: Conclusion

Here we explore the main conclusions from the study, and we make recommendations to improve the use of several activities.

5.1 Contributions of the study

Combining Labatorials and RW in the way they were sequenced in this study improved students understanding of forces and motion. This improvement was detected form the FCI scores, the interviews of students, the CMs and teachers' comments. The approach in the study to teaching dynamics in high school produced an overall medium normalized gain on the FCI scores similar to that of other Interactive Engagement methods. The study also corroborated that strong students gained more than weak students. This gain occurred whether students were enrolled in advanced or in regular classes. It is essential to note that such results were obtained with little to no disruption to the preparations and time dedicated to implementing our approach, which we believe is the greatest achievement of this study. It linked research to practice in a manner available to a regular high school physics class with minimum equipment and minimum preparations.

Studies often conclude that students' understanding of forces and motion is not adequate and they make a recommendation here or there in an attempt to improve it. We offered a complete set of activities to address forces and motion in contrast to techniques to tackle one part or the other of the material. A flexible process leading to the result is described thus facilitating its adoption or adaptation by interested teachers. Also, what we proposed does not take up all the course time which leaves the high school teacher room for lectures or to focus on certain exercises or requirements from the institution, curriculum, high stakes standardized exams or future levels.

We believe one can get students to understand the concept of force within the Newtonian model using a gradual and evolving repetitive approach to the concept of force. Where students are brought to consider the importance of the agent (the body exerting the force) and its use through different situations before reaching the two-way motion of the fan cart and the decay model. This repetition of the same concept viewed from different angles is emphasised by Savinainen et al. (2017). Lattery (2016) argued students may have a body of connected difficulties which tackling cannot merely be done in a single blow. Therefore, students should be permitted to gradually build their knowledge of forces and motion and of the importance the agent plays in resolving their difficulties. Our study focuses on that process through several tools: the representation of the force, the course documents and the Labatorials leading to the fan cart experiment. When students' analysis of the Fan cart experiment did not correspond to the Newtonian theory, their change to a description corresponding to the Newtonian framework, was seamless. The fan cart experiment was an added advanced stage of learning. On its own it can be problematic. Our results have shown that the combination of RW and Labatorials and the order with which they were introduced brings students closer to the Newtonian view of the force.

Our results show that there is value in systematically asking students to draw the vectors corresponding to the resultant force, velocity and acceleration along with any free body diagram, especially those where motion is not so obviously analyzed. This request helped students overcome or change to a description corresponding to the Newtonian framework, from an array of misconceptions such as the force is in the direction of motion or, that a constant force means a constant velocity. This request also helped students reach the conclusion expressed by MET18-

R62 which is that forces should be drawn independently of motion. One example where this recommendation plays a decisive role is in the two-way motion of the fan cart. In the first part of the trip, when the hand is no longer pushing the cart, some students tend to keep the force of the hand. In this case, drawing the resultant force, velocity and acceleration show the student that the resultant force is opposite to the acceleration. In addition, assuming that drawing all the vectors was previously done in other activities, students would have come across the situation where the body is accelerating when the resultant force is in the same direction as the velocity which is not the case when the hand leaves the cart. We are not arguing that drawing the resultant force, velocity and acceleration will prevent errors and difficulties. However, we are arguing, based on our results, that drawing all the vectors will equip students to tackle such situations.

What is clear from the interviews is that many students appear to have developed an almost complete understanding of the two-way motion of the fan cart while some students still struggle with the difficulties related to forces. We estimate that those who better understood the two-way motion of the fan cart were engaged in the discussions with their peers and teacher during the Labatorials and in the classroom. It was clear from the interviews that they had the mental sequence clear in their heads.

Admitting that both teachers and researchers have to do their part in adapting to one another, We argue that research has to do more to accommodate teachers than teachers to accommodate research. Teachers are on the front line of education and they are subject to numerous restrictions. They are capable of making adjustments but are limited by their extent. Researchers are better positioned to develop ways to deploy their findings in school settings. Those can be developed in collaboration with teachers. Researchers are invited to reflect on the practical deployment of their findings whenever those findings can be of practical use for the teachers.

5.2 About Labatorials

Our approach to using Labatorials and RW is not designed to prepare students for traditional tests. It is however designed to leave teachers time to work on preparing students for future requirements and to satisfy institutional and teaching constraints.

Teachers and students greatly appreciated one aspect of Labatorials which is that students can ask for clarifications during their work and discuss issues with their teachers. Teachers appreciated that they could guide their students without carrying the burden of not guiding them for the sake of evaluating. Students realized that the focus is on their understanding of the material and not on what they put on a piece of paper which dictates their grade. At first, they found this aspect strange, a bit unreal, but they very soon appreciated its effect. They know that the teacher is not looking for the right answer to reward them. Instead, they actively work towards understanding the concepts and how they relate to one another which is the main reward for both students and teacher. Strangely, this point must also be explained for many teachers, luckily for the researcher, not those teachers participating in this study.

Some teachers might find that five Labatorials are difficult to integrate into their planning. In this case, the second Labatorial, which is mainly about forces and vector sum, can be removed. Thus, leaving the first Labatorial about forces and one Labatorial for each of Newton's laws.

About forming teams for Labatorials, Azmitia and Montgomery (1993) found that when teams are made of friends, they were more likely to engage in discussions, justify their solutions and check their answers more that teams formed of members who did not know each other. This result might help guide teachers in teams' formation. An interesting practical advantage to Labatorials, compared to traditional labs, is that because there are no lab reports to be completed after the Labatorials, teams can be relatively easily formed without taking into account any coordination between their members to produce a lab report after the lab session. This may not be a major issue at the university level, but in high school it plays a role because students' mobility after school sessions is dependent on their parents and where they live.

5.3 The fan cart activity: an integrating one

This section is dedicated to highlighting the value of the second activity in Labatorial 5 (Appendix B) observed during the study. This activity is intended as an introduction to activity 3 which is about the vertical toss. However, it has proven to be more valuable than the vertical toss activity. Most of the analysis and the discoveries made by the students take place in this activity and they are then moved or translated to the third activity. As Teacher-1 expressed in one of the feedback conversations during the study: "if for whatever reason all must go or things should change, this activity must remain".

The value in this activity derives from how it integrates concepts and processes and how it tackles misconceptions. The concepts it integrates come from both kinematics and dynamics and they cover graphic (velocity-time and acceleration-time graphs) and vector representations (of velocities, accelerations and forces). The activity is an opportunity for students to put almost all what they saw in the mechanics course in a single situation which also covers some of the most daunting misconceptions Mechanics has to offer. One must admit that this activity benefits from previous activities covering the concepts it integrates. As already mentioned, its values lie in the integration of concepts more than in their introduction. This activity can be used as a stand-alone activity; however, given the “density” of its content and the highlighted importance of iterations and multiple exposures to concepts, it is better introduced gradually through several steps.

We would like to emphasize the importance of asking students to draw a velocity-time graph and an acceleration-time graph of the motion of the fan cart, and on asking students to specify on both graphs, when they started to push the cart and when they stopped pushing it. Identifying the acceleration in the velocity-time graph as the slope and highlighting its sign can also be a powerful link that helps students in integrating concepts seen in kinematics with this situation in dynamics.

5.4 Improving the Concept Map

The CM is used as an evaluation tool and its use in this study brought insight into how students connect the different concepts seen in the course. A CM is also used as a formative/teaching tool which can help students better connect between concepts and improve their general understanding of the material.

The scope of a concept map is limited by the scope of its boxes (the concepts they contain). Usually, students are given a set of concepts which are decided by the teacher. The students are supposed to relate those concepts with propositions (labeled arrows). Completing a concept map requires some training (or very clear instructions with examples, but training is preferred) to get the best results. Students may write a proposition in its simplest form because this is the way they see it. For example, they might say that a force “can produce” a constant acceleration, which is not wrong, however, it lacks precision because the student did not specify the conditions under which a constant acceleration is reached. Instead of “can produce” a better label would be “if constant, produces”. A student might know that but might not be tempted to go into this much detail if not prompted to do so. We believe that the most rigorous propositions can be attained if students are trained or directed to produce them.

The purpose of this study is not to improve CMs in general, however, the advice offered here is intended to improve any future use of the CM in conjunction with Labatorials. The same advice can be extrapolated to other applications.

Students completed successfully, in general, their CMs without any prior training on how CMs should be completed. Nonetheless, we propose the following improvements to the guidelines provided on producing a CM, to the example given and to the process followed:

- Assigning a course grade to the CM can make the students take it more seriously.
- Replacing the box labeled “Velocity Changing”, with one labeled “Velocity changing not at a constant rate” to create a clear distinction from the one labeled “Velocity changing at a constant rate”.
- Removing the boxes labeled “Force” and “Body exerting a force” and keep only the box labeled “Body subjected to a force”.
- Adding a box labeled “$\sum F = 0$” and another labeled “$\sum F = constant$”.
- Insisting in the guidelines that ALL arrows should labeled, not just with any general and safe label, but to commit to the label which offers the most complete description of the relation. That a label can be a condition or an equation, which when satisfied, the relation becomes possible.

- Modifying the provided example to include arrows labeled with mathematical expressions.
- Planning a classroom activity, during which individual CMs are discussed in small groups. In preparation for this activity, students would be asked to design a CM as a graded homework. The individual CMs are then compared and discussed, in a classroom activity, in teams of three to five students. Each team will come up with a single CM which will be presented to the class at the end of the session (or shared on a drive). A class CM might eventually emerge from such an activity. This activity can be done for each chapter or each part like dynamics, Kinematic, Energy or Optics. A school year might end with 5 or 6 CM which can (and in some cases, must) include formulas. Students in general appreciate such synthesis, especially top students. It’s a low-impact activity for the teacher and a rich and practical summative activity.

There are several methods to rate CMs, we believe that the most suited for CMs on forces and motion is the relational method with a master map (used in this study) which consists of identifying propositions in students’ CMs based on those in the master map. A classroom activity like the one proposed above can spare the teacher from rating CMs or from rating a large number of CMs. It is also worth noting that asking students to complete CMs using software (there are several available) can increase the clarity of a concept map and improve its appearance which would make it easier to rate. Software can also be configured to log relations between concepts thus facilitating their rating.

5.5 Advice to the physics teacher

Here we compile several recommendations to the physics teacher. They can be helpful for teachers in using Labatorials or in managing the physics course in general.

- It would be good to change teams from one Labatorial to another. Some top students do not like to remain bound to the same teammates for extended periods and situations.
- A Labatorial activity can be based on a video, an article, a documentary, a phenomenon or an event. The use of computer simulations is also recommended to diversify the approach. That is to say that the activity does not have to be bound to the traditional lab equipment. One can even make use of students' phones for certain Apps or for taking videos in slow motion. A Labatorial's structure is flexible enough to integrate activities of varied forms using different technologies. Teachers can create their progression of activities with the end in mind. What we included in our Labatorials are what we think is convenient for the Physics syllabus in the province of Quebec.
- There are activities which we strongly recommend however they are not exclusive. If teachers want to use other activities, we recommend that students always represent the resultant force, the acceleration and the velocity as vectors along with the free body diagrams. As well as highlighting whether the body is speeding up, slowing down or moving at a constant speed.
- Always treat the acceleration as a vector quantity. Always represent it next to the force diagram or when drawing parabolic motion. Always ask the students to draw the acceleration vector especially when the body is accelerating.

- Always compare the orientation or sign of the acceleration to those of the velocity to conclude whether the body is speeding up or slowing down. This could establish a good habit that steers students away from assuming that a body is slowing down simply because the acceleration is negative. Always break the habit that when the acceleration is positive then the body is speeding up. It must never be taken for granted. Help the students become wary vis-à-vis this detail. Some students might find it difficult to draw the acceleration. To help them, ask them to draw two consecutive velocity vectors, and then compare those vectors. The difference vector between those vectors indicates the orientation of the acceleration. Have them draw it at every chance they get, particularly in free fall, vertical toss and the parabolic toss.
- Do free fall after dynamics. Usually, teachers cover the projectile motion, and the vertical toss, as a part of kinematics which is completed before dynamics. We believe that there is more value in doing the projectile motion after dynamics for the following reasons:
    - The justification of the value of the acceleration is lacking if done before dynamics, and no longer necessary if done after dynamics. After dynamics, the projectile motion (in one or two dimensions) becomes a consequence of Newton's Second Law. When doing free fall before dynamics, if a student asks why the acceleration is constant, then the teacher would ask the student to trust the teacher and that the justification will be covered in the following part (dynamics). A more intriguing question students ask when they see parabolic motion before dynamics is: why is the acceleration constant when the trajectory is parabolic? Such a question is difficult to answer or justify without Newton's second law.

  - Students would have acquired more mastery of vectors to deal with the parabolic motion, especially the analysis of the velocities, their projections and their rate of change.
  - Covering the projectile motion after dynamics offers rich opportunities to integrate both kinematics and dynamics while studying bodies in motion in one dimension and two dimensions.
- The teaching of inertia and Newton's First Law, in general, must be accompanied with drawing free body diagrams. Many teachers base their work on Newton's First Law on what is found in the textbooks. With hardly any free body diagrams drawn. The first law is treated as an expression that describes the tendency of a body to keep going. It would help to specify that when the sum of forces is zero, then the velocity is constant or null depending on the initial state of motion of the body.
- Using students as a TA can be explored. Although it might be challenging to organize, it would however be an incentive for top students or for students looking for an extra grade. They would be willing to put the extra effort. The student-TA can be rotated throughout the school year.

5.6 Limitations

Any study has its limitations especially those involving unpredictable factors like humans. Although we are confident of the positive impact of the combination of Labatorials with RW in high school some factors listed here certainly lead to variations in the outcome.

The school environment, institutional constraints and departmental work play a fundamental role in the implementation of any process or approach. Not all the teachers have the same methods and they don't all interact with their students in the same way. Their experience can also play a major role in their efficiency in either adopting or implementing the methods in our study. These differences may play a role in managing the discussions in the Labatorials or the classroom, in how they apply the elicit and challenge technique or the bridging technique. These differences should not be considered flaws. This diversity in dealing with different students in different situations and the ability to tailor answers to questions based on students' needs is one of the advantages of Labatorials. Within the context of studies, it could be a factor causing variations in the outcomes.

Our design leaves room for teachers to follow up on Labatorials with exercises and classwork to satisfy their needs. This content is not covered by the study and could have played a role in shaping the results we obtained

Although three teachers, other than the researcher, and their students participated in this study, the researcher's students, which are all girls, account for half of the participants. The researcher's students account for four of the twelve interviewed students and all the concept maps collected. Apart from the concept maps, no notable discrepancies were detected in the results. However, the dominant portion of participants are associated with the researcher, and the fact that most participants in the study are girls could be considered as a limitation to our study.

5.7 The combination works

Our approach to teaching dynamics which combines Labatorials and RW has shown to be effective in improving students understanding of forces and motion. Results and comments from teachers and students indicate that this combination is both usable and efficient and that it contributed to closing the gap between research and practice, which was one of the main goals of the study. This study provides a real choice for high school teachers to tackle this challenging part of physics. Teaching the concept of force is accompanied by daunting difficulties. The interviews and the FCI results indicate that the sequencing of activities, and their emphasis on key aspects of this concept, bring students closer to the Newtonian model of the force. The analysis of the 3 items of the FCI show that this shift toward Newtonian ideas is strong for most participants and not just the interviewed students. The improvement in the CM following the study corroborates the shift in students' knowledge and projects coherence between their concepts. Such a coherence was lacking in the pre-CM. The positive results we obtained are strengthened by the variety of the evaluation tools which better situates our study as a valid contender to successfully introduce dynamics in high school. What makes our approach even more valuable is its minimal disruption to the high school environment and its high potential to be integrated with little preparations. The combination of Labatorials and RW, and potentially the integration of CM as a teaching tool, can play a major role in improving students understanding of dynamics.

5.8 Where do we go from here?

We hope that future studies aid in closing the gap between researchers and the classroom teachers and aid in providing coherent approaches, as teaching units, which can be used by teachers in high school and beyond. These are some possibilities for future studies:

- Combining RW and Labatorials in a unit to teach waves and optics is surely useful for high school teachers and students.
- We believe that it would be valuable to investigate the impact of using concept maps as a teaching tool and how those maps can affect the connections formed by students.

- Evaluate how the use of the force notation, with the agent and type of force appearing on it, affect students' abilities to draw free body diagrams.

REFERENCES

Abrams, E., Southerland, S. A., & Evans, C. A. (2007). Inquiry in the classroom: Necessary components of a useful definition. *Inquiry in the classroom: Realities and Opportunities. Greenwich, CT: Information Age Publishing*.

Ahrensmeier, D. (2013). A practical application of Physics Education Research-informed teaching interventions in a first-year physics service course. *Journal of Technical Education (JOTED), 1*(1).

Ahrensmeier, D., Donev, J., Hicks, R., Louro, A., Stafford, R., Borvayeh, L., & Thompson, R. (2009). Towards concept-based instruction with blended learning in Labatorials. *APS, 11*, G4. 008.

Ahrensmeier, D., Thompson, R. I., Wilson, W. J. F., & Potter, M. E. (2012). Labatorials - A New Approach to Teaching Electricity and Magnetism to Students in Engineering. 1-2.

Angell, C., Guttersrud, O., Henriksen, E. K., & Isnes, A. (2004). Physic: Frightful, but fun. Pupils' and teachers' views of physics and physics teaching. *Science Education, 88*(5), 683-706.

Arons, A. B. (1993). Guiding insight and inquiry in the introductory physics laboratory. *The Physics Teacher, 31*(5), 278-282.

Arons, A. B., & Miner, T. D. (1990). A guide to introductory physics teaching. *PhTea, 28*(6), 426-426.

Aulls, M. W. (2002). The Contributions of Co-Occurring Forms of Classroom Discourse and Academic Activities to Curriculum Events and Instruction. *Journal of Educational Psychology, 94*(3), 520-538.

Austin, L. B., & Shore, B. M. (1994). The use of concept mapping as an instructional strategy in college level physics. *Scientia paedagogica experimentalis*.

Austin, L. B., & Shore, B. M. (2011). Concept Mapping of High and Average Achieving Students and Experts. *European Journal of High Ability, 4450*(July).

Azmitia, M., & Montgomery, R. (1993). Friendship, transactive dialogues, and the development of scientific reasoning. *Social development, 2*(3), 202-221.

Baird, J. R., & Northfield, J. R. (1995). *Learning from the PEEL experience*: School of Graduate Studies, Faculty of Education, Monash University.

Bao, L., Hogg, K., & Zollman, D. (2002). Model analysis of fine student models: An example with Newton's third law. *American Journal of Physics, 70*(7), 766-778.

Barmby, P., Kind, P. M., & Jones, K. (2008). Examining changing attitudes in secondary school science. *International Journal of Science Education, 30*(8), 1075-1093.

Baxter, G. P., Elder, A. D., & Glaser, R. (1996). Knowledge-based cognition and performance assessment in the science classroom. *Educational Psychologist, 31*(2), 133-140.

Beichner, R. J., Saul, J. M., Allain, R. J., Deardorff, D. L., & Abbott, D. S. (2000). *Introduction to SCALE-UP: Student-Centered Activities for Large Enrollment University Physics*. Retrieved from

Biesta, G. (2007). Bridging the gap between educational research and educational practice: The need for critical distance. *Educational Research and Evaluation, 3*(13), 295-301.

Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability (formerly: Journal of Personnel Evaluation in Education), 21*(1), 5.

Blakely, C. H., Mayer, J. P., Gottschalk, R. G., Schmitt, N., Davidson, W. S., Roitman, D. B., & Emshoff, J. G. (1987). The fidelity-adaptation debate: Implications for the implementation of public sector social programs. *American journal of community psychology, 15*(3), 253-268.

Blanchard, M. R., Southerland, S. A., Osborne, J. W., Sampson, V. D., Annetta, L. A., & Granger, E. M. (2010). Is inquiry possible in light of accountability?: A quantitative comparison of the relative effectiveness of guided inquiry and verification laboratory instruction. *Science Education, 94*(4), 577-616.

Bogartz, R. S. (1994). The Future of Dynamic Systems Models in Developmental Psychology in the Light of the Past. *Journal of Experimental Child Psychology, 58*(2), 289-319.

Britton, J., Burgess, T., Martin, N., McLeod, A., & Rosen, H. (1975). The de velopment of writing abilities. *London: Macmlllan*.

Broekkamp, H., & van Hout-Wolters, B. (2007). The Gap between Educational Research and Practice: A Literature Review, Symposium, and Questionnaire. *Educational Research and Evaluation, 13*(3), 203-220.

Brown, D. E. (1989). Students' concept of force: the importance of understanding Newton's third law. *Physics Education, 24*, 353-358.

Brown, D. E., & Hammer, D. (2009). Conceptual change in physics *International handbook of research on conceptual change* (pp. 127-154): Routledge.

Brown, D. E., & Hammer, D. (2009). Conceptual change in physics *International handbook of research on conceptual change* (pp. 155-182): Routledge.

Brownlee, J., Walker, S., Lennox, S., Exley, B., & Pearce, S. (2009). The first year university experience: using personal epistemology to understand effective learning and teaching in higher education. *Higher Education, 58*(5), 599-618.

Bruner, J. S. (1975). The ontogenesis of speech acts. *Journal of child language, 2*(1), 1-19.

Bruner, J. S. (1986). *Actual minds, possible worlds*. Cambridge, Mass.: Harvard University Press.

Burkhardt, H., & Schoenfeld, A. H. (2003). Improving educational research: Toward a more useful, more influential, and better-funded enterprise. *Educational Researcher, 32*(9), 3-14.

Byra, M., & Coulon, S. C. (1994). The effect of planning on the instructional behaviors of preservice teachers. *Journal of Teaching in Physical Education, 13*(2), 123-139.

Caravita, S., & Halldén, O. (1994). Re-framing the problem of conceptual change. *Learning and Instruction, 4*(1), 89-111.

Carlone, H. B. (2003). Innovative science within and against a culture of "Achievement". *Science Education, 87*(3), 307-328.

Champagne, A. B., Klopfer, L. E., & Anderson, J. (1980). Factors influencing the learning of classical mechanics. *American Journal of Physics, 48*, 1074-1079.

Chang, M.-L. (2009). An appraisal perspective of teacher burnout: Examining the emotional work of teachers. *Educational psychology review, 21*(3), 193-218.

Chen, J. (2017). Personal Epistemology of Engineering Students.

Chi, M. T., Slotta, J. D., & De Leeuw, N. (1994). From things to processes: A theory of conceptual change for learning science concepts. *Learning and Instruction, 4*(1), 27-43.

Chi, M. T. H. (2013). Two Kinds and Four Sub-Types of Misconceived Knowledge, Ways to Change it, and the Learning Outcomes *International handbook of research on conceptual change* (pp. 47-70).

Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and Representation of Physics Problems by Experts and Novices*. *Cognitive Science, 5*(2), 121-152.

Chu, H.-E., Treagust, D. F., & Chandrasegaran, A. (2008). Naïve students' conceptual development and beliefs: The need for multiple analyses to determine what contributes to student success in a university introductory physics course. *Research in Science Education, 38*(1), 111-125.

Cisero, C. a. (2006). Does Reflective Journal Writing Improve Course Performance? *College Teaching, 54*(2), 231-236.

Clark, C., & Yinger, R. (1979). Teachers' thinking. *Research on teaching: concepts, findings, and implications*, 231-263.

Clark, D., & Jorde, D. (2004). Helping students revise disruptive experientially supported ideas about thermodynamics: Computer visualizations and tactile models. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 41*(1), 1-23.

Clark, D. B. (2006). Longitudinal conceptual change in students' understanding of thermal equilibrium: An examination of the process of conceptual restructuring. *Cognition and Instruction, 24*(4), 467-563.

Clement, J. (2000). Analysis of clinical interviews: Foundations and model viability. *Handbook of research design in mathematics and science education*, 547-589.

Clement, J. (2008). *Creative model construction in scientists and students : the role of imagery, analogy, and mental simulation*: Springer Science & Business Media.

Clement, J., & Rea-Ramirez, M. A. (2008). *Model based learning and instruction in science* Models and modeling in science education ; vol. 2.

Colburn, A. (2000). An inquiry primer. *Science scope, 23*(6), 42-44.

Collins, A., Brown, J. S., & Newman, S. E. (1988). Cognitive apprenticeship: Teaching the craft of reading, writing and mathematics. *Thinking: The Journal of Philosophy for Children, 8*(1), 2-10.

Connolly, P. (1989). Writing and the ecology of learning. *Writing to learn mathematics and science*, 1-14.

Conradty, C., & Bogner, F. X. (2012). Knowledge presented in concept maps: Correlations with conventional cognitive knowledge tests. *Educational Studies, 38*(3), 341-354.

Crawford, B. A. (2007). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research In Science Teaching, 44*(4), 613-642.

Crouch, C., Fagen, A. P., Callan, J. P., & Mazur, E. (2004). Classroom demonstrations: Learning tools or entertainment? *American Journal of Physics, 72*(6), 835-838.

Cullota, E. (1992). 'The Calculus of Educational Reform. *Science, 255*, 1060-1062.

Cummings, K., Marx, J., Thornton, R., & Kuhl, D. (1999). Evaluating innovation in studio physics. *American Journal of Physics, 67*(S1), S38-S44.

Darling-Hammond, L. (1990). Teaching and knowledge: Policy issues posed by alternate certification for teachers. *Peabody Journal of education, 67*(3), 123-154.

De Lozano, S. R., & Cardenas, M. (2002). Some learning problems concerning the use of symbolic language in physics. *Science & Education, 11*(6), 589-599.

De Nobile, J. J., & McCormick, J. (2008). Organizational communication and job satisfaction in Australian Catholic primary schools. *Educational Management Administration & Leadership, 36*(1), 101-122.

DeAngelis, K. J., & Presley, J. B. (2011). Toward a more nuanced understanding of new teacher attrition. *Education and Urban Society, 43*(5), 598-626.

Dearing, J. W., Dede, C., Boisvert, D., Carrese, J., Clement, L., Craft, E., . . . McNeel, D. (2015). How educational innovators apply diffusion and scale-up concepts *Scaling educational innovations* (pp. 81-104): Springer.

DiCicco, M., Jordan, R., & Sabella, L. (2019). Conducting the “Business of Teaching”: Expectations of Non-instructional Tasks of Beginning STEM Teachers. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas, 92*(6), 210-223.

diSessa, A. A. (1983). Phenomenology and the evolution of intuition. In D. Gentner, Stevens, A. L. (Ed.), *Mental models* (pp. 15-33). Hillsdale and London: Lawrence Erlbaum.

diSessa, A. A. (1988). Knowledge in pieces. In G. F. P. P. (Eds.) (Ed.), *Constructivism in the computer age* (pp. 49-70). Mahwah, NJ: Erlbaum.

diSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and Instruction, 10*(2-3), 105-225.

diSessa, A. A. (2008). A bird´s-eye view of the "pieces" vs. "coherence" controversy (from the "pieces" side of the fence). In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 35-60). New York: Routledge.

diSessa, A. A. (2018). *A friendly introduction to “knowledge in pieces”: Modeling types of knowledge and their roles in learning.* Paper presented at the Invited lectures from the 13th international congress on mathematical education.

diSessa, A. A., Gillespie, N. M., & Esterly, J. B. (2004). Coherence versus fragmentation in the development of the concept of force. *Cognitive Science, 28*(6), 843-900.

Drabick, D. A. G., Weisberg, R., Paul, L., & Bubier, J. L. (2007). Keeping it short and sweet: Brief, ungraded writing assignments facilitate learning. *Teaching of Psychology, 34*(3), 172-176.

Driver, R. (1988). Theory into Practice 2: A constructivist approach to curriculum development. In P. Fensham (Ed.), *Development and dilemmas in Science Education* (pp. 133-149). London, New York, Philadelphia: The Falmer Press.

Driver, R., Asoko, H., Leach, J., Scott, P., & Mortimer, E. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*(7), 5-12.

Driver, R., & Easley, J. A. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education, 5*, 61-84.

Driver, R., Rushworth, P., Squires, A., & Wood-Robinson, V. (2005). *Making sense of secondary science: Research into children's ideas*: Routledge.

Duit, R., & Treagust, D. F. (2003). Conceptual Change: A Powerful Framework for Improving Science Teaching and Learning. *International Journal of Science Education, 25*(6), 671-688.

Duit, R. H., & Treagust, D. F. (2012). Conceptual change: Still a powerful framework for improving the practice of science instruction *Issues and challenges in science education research* (pp. 43-54): Springer.

Edmondson, K. M. (2005). Assessing science understanding through concept maps *Assessing science understanding* (pp. 15-40): Elsevier.

Edwards, S., & Mercer, N. (1987). *Common Knowledge*. London: Methuen.

Eger, M. (1993a). Hermeneutics as an approach to science: Part I. *Science & Education, 2*(1), 1-29.

El-Helou, J. (2016). *Reflective writing for a better understanding of scientific concepts in high school* (Masters' Thesis), Concordia University.

El-Helou, J., & Kalman, C. S. (2018). Reflective Writing for a Better Understanding of Scientific Concepts in High School. *The Physics Teacher, 56*(2), 88-91.

Elbow, P. (1973). The Doubting Game and the Believing Game–An Analysis of the Intellectual Enterprise." Appendix Essay in Writing Without Teachers: New York: Oxford University Press.

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100*(3), 363.

Fazio, C., & Battaglia, O. R. (2019). Conceptual understanding of Newtonian mechanics through cluster analysis of FCI student answers. *International Journal of Science and Mathematics Education, 17*(8), 1497-1517.

Fimian, M. J., & Blanton, L. P. (1987). Stress, burnout, and role problems among teacher trainees and first-year teachers. *Journal of Occupational Behaviour, 8*(2), 157-165.

Flavell, J. H. (1976). Metacognitive aspects of problem solving. In L. B. Resnick (Ed.), *The nature of intelligence*. Hillsdale, N. J.: Lawrence Erlbaum Association.

Forster, M. (2009). Friedrich Daniel Ernst Schleiermacher. *Stanford Encyclopedia of Philosophy*, 1-60.

Forzani, F. M. (2014). Understanding "core practices" and "practice-based" teacher education: Learning from the past. *Journal of Teacher Education, 65*(4), 357-368.

Fulwiler, T. (1987). *The Journal Book*. Portsmouth, NH: Heinemann.

Gadamer, H. G. (2004). *Truth and method*. London: Continuum.

Gore, J. M., & Gitlin, A. D. (2004). [RE] Visioning the academic–teacher divide: Power and knowledge in the educational community. *Teachers and teaching, 10*(1), 35-58.

Griffard, P. B., & Wandersee, J. H. (2001). The two-tier instrument on photosynthesis: What does it diagnose? *International Journal of Science Education, 23*(10), 1039-1052.

Griffey, D. C., & Housner, L. D. (1991). Differences between experienced and inexperienced teachers' planning decisions, interactions, student engagement, and instructional climate. *Research Quarterly for Exercise and Sport, 62*(2), 196-204.

Gunel, M., Hand, B., & McDermott, M. A. (2009). Writing for different audiences: Effects on high-school students' conceptual understanding of biology. *Learning and Instruction, 19*(4), 354-367.

Gunstone, R. F., & White, R. T. (1981). Understanding of gravity. *Science Education, 65*, 291-299.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66*(1), 64-74.

Halloun, I. A. (2007). *Modeling theory in science education* (Vol. 24): Springer Science & Business Media.

Halloun, I. A., & Hestenes, D. (1985). The initial knowledge state of college physics students. *American Journal of Physics, 53*(11), 1043-1055.

Hammer, D., & Elby, A. (2003). Tapping epistemological resources for learning physics. *The Journal Of The Learning Sciences, 12*(1), 53-90.

Hammersley, M. (2002). *Educational research, policymaking and practice*.

Hardy, I., Jonen, A., Moller, K., & Stern, E. (2006). Effects of Instructional Support within Constructivist Learning Environments for Elementary School Students' Understanding of "Floating and Sinking". *Journal of Educational Psychology, 98*(2), 307-326.

Hargreaves, D. (2007). Teaching as a research-based profession: possibilities and prospects (The Teacher Training Agency Lecture 1996). *Educational research and evidence-based practice*, 3-17.

Harrison, A. G., Grayson, D. J., & Treagust, D. F. (1999). Investigating a grade 11 student's evolving conceptions of heat and temperature. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 36*(1), 55-87.

Hattie, J. (2009). *Visible learning : a synthesis of over 800 meta-analyses relating to achievement*. London ;: Routledge.

Hemsley-Brown, J., & Sharp, C. (2003). The use of research to improve professional practice: A systematic review of the literature. *Oxford Review of Education, 29*(4), 449-471.

Henderson, C. (2002). Common concerns about the force concept inventory. *The Physics Teacher, 40*(9), 542-547.

Hestenes, D. (1997). *Modeling methodology for physics teachers.* Paper presented at the AIP conference proceedings.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher, 30*(3), 141-158.

Hewson, P. W., & Hewson, M. (1984). The role of conceptual conflict in conceptual change and the design of science instruction. *Instructional Science*.

Hill, H. C., Rowan, B., & Ball, D. L. (2005). Effects of teachers' mathematical knowledge for teaching on student achievement. *American Educational Research Journal, 42*(2), 371-406.

Hobson, A., Malderez, A., Tracey, L., Homer, M., Mitchell, N., Biddulph, M., . . . Roper, T. (2007). Newly qualified teachers' experiences of their first year of teaching. *Findings from Phase III of the Becoming a Teacher Project*.

Hodson, D. (1993). Re-thinking Old Ways: Towards A More Critical Approach To Practical Work In School Science. *Studies in Science Education, 22*(1), 85-142.

Hofer, B. K. (2000). Dimensionality and disciplinary differences in personal epistemology. *Contemporary educational psychology, 25*(4), 378-405.

Hogan, K., Nastasi, B. K., & Pressley, M. (1999). Discourse patterns and collaborative scientific reasoning in peer and teacher-guided discussions. *Cognition and Instruction, 17*(4), 379-432.

Holton, G. J., Rutherford, F. J., & Watson, F. G. (1981). *Project Physics: Resource Book*: Holt, Rinehart and Winston.

Housner, L. D., & Griffey, D. C. (1985). Teacher cognition: Differences in planning and interactive decision making between experienced and inexperienced teachers. *Research Quarterly for Exercise and Sport, 56*(1), 45-53.

Huang, X., & Kalman, C. S. (2012). A Case Study on Reflective Writing. *Journal of College Science Teaching, 42*(1), 92-92.

Hubber, P., Tytler, R., & Haslam, F. (2010). Teaching and learning about force with a representational focus: Pedagogy and teacher change. *Research in Science Education, 40*(1), 5-28.

Ioannides, C., & Vosniadou, S. (2002). The changing meanings of force. *Cognitive science quarterly, 2*(1), 5-62.

Jacobson, M. J., & Wilensky, U. (2006). Complex systems in education: Scientific and educational importance and implications for the learning sciences. *The Journal Of The Learning Sciences, 15*(1), 11-34.

Jauhiainen, J., Koponen, I. T., & Lavonen, J. (2006). Teachers' Beliefs about the Role of Interaction in Teaching Newtonian Mechanics and Its Influence on Students' Conceptual Understanding of Newton's Third Law. *Science Education International, 17*(3), 149-160.

Jenkins, E. W., & Nelson, N. (2005). Important but not for me: Students' attitudes towards secondary school science in England. *Research in Science & Technological Education, 23*(1), 41-57.

Jimenez, V. J. d. D., & Perales, P. F. J. (2001). Graphic representation of force in secondary education: Analysis and alternative educational proposals. *Physics Education, 36*(3), 227-235.

Kalman, C. S. (2001). Teaching students to solve quantitative problems in science courses by writing their way into the solution. *The Successful Professor sample issue*, 3-4.

Kalman, C. S. (2008). *Successful Science and Engineering Teaching: theoretical and learning perspectives* (Vol. 3): Springer.

Kalman, C. S., Aulls, M. W., Rohar, S., & Godley, J. (2008). Students' perceptions of reflective writing as a tool for exploring an introductory textbook. *Journal of College Science Teaching, 37*(4), 74.

Kalman, C. S., La Braca, F., & Sobhanzadeh, M. (2020). *Comparison of Labatorials and Traditional Physics Labs*. ASEE'S Virtual Conference.

Kalman, C. S., Sobhanzadeh, M., Thompson, R., Ibrahim, A., & Wang, X. (2015). Combination of interventions can change students' epistemological beliefs. *Physical Review Special Topics - Physics Education Research, 11*(2).

Kalman, C. S., Sobhanzadeh, M., Thompson, R., Ibrahim, A., & Wang, X. (2015). Combination of interventions can change students' epistemological beliefs. *Physical Review Special Topics-Physics Education Research, 11*(2), 020136.

Kalman, J., & Kalman, C. (1996). Writing to learn. *American Journal of Physics, 64*(7), 954-954.

Karabenick, S. A., Woolley, M. E., Friedel, J. M., Ammon, B. V., Blazevski, J., Bonney, C. R., . . . Kempler, T. M. (2007). Cognitive processing of self-report items in educational research: Do they think what we mean? *Educational Psychologist, 42*(3), 139-151.

Kariotoglou, P., Spyrtou, A., & Tselfes, V. (2009). How student teachers understand distance force interactions in different contexts. *International Journal of Science and Mathematics Education, 7*(5), 851-873.

Kennedy, M. (2016). Parsing the practice of teaching. *Journal of Teacher Education, 67*(1), 6-17.

Kennedy, M. M. (1997). The connection between research and practice. *Educational Researcher, 26*(7), 4-12.

Kessels, U., Rau, M., & Hannover, B. (2006). What goes well with physics? Measuring and altering the image of science. *British Journal of Educational Psychology, 76*(4), 761-780.

Khanam, W. N., & Kalman, C. S. (2016). Implementation and Evaluation of the Course Dossier Methodology. *The Canadian Journal for the Scholarship of Teaching and Learning, 8*(1).

Kozminski, J., Lewandowski, H., Beverly, N., Lindaas, S., Deardorff, D., Reagan, A., . . . Williams, J. (2014). AAPT recommendations for the undergraduate physics laboratory curriculum. *AAPT: College Park, MD, USA*.

Kuhn, T. S. (1970). *The Structure of Scientific Revolutions, 2nd enl. ed*: University of Chicago Press.

Kunter, M., Klusmann, U., Baumert, J., Richter, D., Voss, T., & Hachfeld, A. (2013). Professional competence of teachers: Effects on instructional quality and student development. *Journal of Educational Psychology, 105*(3), 805.

Kyriacou, C. (2011). Teacher stress: From prevalence to resilience. *Handbook of stress in the occupations*, 161-173.

Ladd, H. F. (2007). Teacher labor markets in developed countries. *The Future of Children*, 201-217.

Larkin, J., McDermott, J., Simon, D. P., & Simon, H. A. (1980). Expert and novice performance in solving physics problems (Vol. 208, pp. 1335-1342): American Association for the Advancement of Science.

Larkin, T., & Budny, D. (2005). *Learning styles in the classroom: approaches to enhance student motivation and learning.* Paper presented at the 6th International Conference on Information Technology Based Higher Education and Training.

Lattery, M. J. (2016). *Deep Learning in Introductory Physics: Exploratory Studies of Model-Based Reasoning*. Charlotte, NC: IAP.

Laws, P. W. (1991). Calculus-based physics without lectures. *Physics Today, 44*(12), 24-31.

Lepper, M. R., Woolverton, M., Mumme, D. L., & Gurtner, J. (1993). Motivational techniques of expert human tutors: Lessons for the design of computer-based tutors. *Computers as cognitive tools, 1993*, 75-105.

Levin, B. (2004). Making research matter more. *education policy analysis archives, 12*, 56.

Levin, J. R., & O'Donnell, A. M. (1999). What to do about educational research's credibility gaps? *Issues in education, 5*(2), 177-229.

Limón, M. (2001). On the cognitive conflict as an instructional strategy for conceptual change: A critical appraisal. *Learning and Instruction, 11*(4-5), 357-380.

Liu, X. (2004). Using concept mapping for assessing and promoting relational conceptual change in science. *Science Education, 88*(3), 373-396.

Mason, L. (1996). An analysis of children's construction of new knowledge through their use of reasoning and arguing in classroom discussions. *International Journal of Qualitative Studies in Education, 9*(4), 411-433.

Mayer, J., & Hillman, S. (1996). Assessing students' thinking through writing. *The Mathematics Teacher, 89*(5), 428.

McCloskey, M. (1983). Naive theories of motion. In D. Gentner, Stevens, A. L. (Ed.), *Mental models* (pp. 299-324). Hillsdale and London: Lawrence Erlbaum.

McClure, J. R., & Bell, P. E. (1990). *Effects of an Environmental Education-Related STS Approach Instruction on Cognitive Structures of Preservice Science Teachers*. University Park, PA, Pennsylvania State University. (ERIC Document Reproduction Services No. ED 341 582).

McClure, J. R., Sonak, B., & Suen, H. K. (1999). Concept map assessment of classroom learning: Reliability, validity, and logistical practicality. *Journal of Research in Science*

Teaching: The Official Journal of the National Association for Research in Science Teaching, 36(4), 475-492.

McDermott, L., & Shaffer, P. (1998). *Tutorials in Introductory Physics*. New York: Prentice Hall.

McDermott, L. C. (1996). *Physics by Inquiry: An Introduction to Physics and the Physical Sciences, Volumes I & II*: John Wiley & Sons.

McDermott, L. C., & Shaffer, P. S. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part I: Investigation of student understanding. *American Journal of Physics, 60*(11), 994-1003.

McDermott, L. C., & Shaffer, P. S. (2002). *Tutorials in Introductory Physics*: Prentice Hall.

McDermott, L. C., Shaffer, P. S., & Somers, M. D. (1994). Research as a guide for teaching introductory mechanics: An illustration in the context of the Atwood's machine. *American Journal of Physics, 62*(1), 46-55.

McDermott, M. (2010). More than writing-to-learn. *Science Teacher, 77*(1), 32-37.

McDermott, M. A., & Hand, B. (2010). A secondary reanalysis of student perceptions of non-traditional writing tasks over a ten year period. *Journal of Research In Science Teaching, 47*(5), 518-539.

McGinnis, J. R., Parker, C., & Graeber, A. O. (2004). A Cultural Perspective of the Induction of Five Reform-Minded Beginning Mathematics and Science Teachers. *Journal of Research In Science Teaching, 41*(7), 720-747.

McIntyre, D. (2005). Bridging the gap between research and practice. *Cambridge Journal of Education, 35*(3), 357-382.

McKenney, S., & Reeves, T. C. (2018). *Conducting educational design research*: Routledge.

McKenney, S., & Schunn, C. D. (2018). How can educational research support practice at scale? Attending to educational designer needs. *British Educational Research Journal, 44*(6), 1084-1100.

MEESR. (2015). *Terms and conditions for obtaining a Quebec teaching licence* www.meesr.gouv.qc.ca: Bibliothèque et Archives nationales du Québec.

Meltzer, D. E. (2005). Relation between students' problem-solving performance and representational format. *American Journal of Physics, 73*(5), 463-478.

Merrill, D. C., Reiser, B. J., Merrill, S. K., & Landes, S. (1995). Tutoring: Guided learning by doing. *Cognition and Instruction, 13*(3), 315-372.

Miller, K., Lasry, N., Chu, K., & Mazur, E. (2013). Role of physics lecture demonstrations in conceptual learning. *Physical Review Special Topics-Physics Education Research, 9*(2), 020113.

Mintzes, J. J., Wandersee, J. H., & Novak, J. D. (2005). *Teaching science for understanding: A human constructivist view*: Academic Press.

Montanero, M., Suero, M. I., Perez, A. L., & Pardo, P. J. (2002). Implicit theories of static interactions between two bodies. *Physics Education, 37*(4), 318-323.

Morse, R. A. (1993). Constant Acceleration: Experiments with a Fan-Driven Dynamics Cart. *Physics Teacher, 31*(7), 436-438.

Muis, K. R., Duffy, M. C., Trevors, G., Ranellucci, J., & Foy, M. (2014). What were they thinking? Using cognitive interviewing to examine the validity of self-reported epistemic beliefs. *International Education Research, 2*(1), 17-32.

Neal, J. W., Mills, K. J., McAlindon, K., Neal, Z. P., & Lawlor, J. A. (2019). Multiple audiences for encouraging research use: Uncovering a typology of educators. *Educational Administration Quarterly, 55*(1), 154-181.

Nersessian, N. J. (2008). Mental modeling in conceptual change. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 391-416). New York: Routledge.

Newman, W. J., Abell, S. K., Hubbard, P. D., McDonald, J., Otaala, J., & Martini, M. (2004). Dilemmas of Teaching Inquiry in Elementary Science Methods. *Journal of Science Teacher Education, 15*(4), 257-279.

Nieminen, P., Savinainen, A., & Viiri, J. (2012). Relations between representational consistency, conceptual understanding of the force concept, and scientific reasoning. *Physical Review Special Topics-Physics Education Research, 8*(1), 010123.

Novak, J. D. (1990). Concept mapping: A useful tool for science education. *Journal of Research In Science Teaching, 27*(10), 937-949.

Novak, J. D., & Cañas, A. J. (2008). The theory underlying concept maps and how to construct and use them (Technical Report IHMC CmapTools 2006-01 Rev 01-2008). *Florida Institute for Human and Machine Cognition*.

Novak, J. D., & Gowin, D. B. (1984). *Learning how to learn*. Cambridge: Cambridge Univerity Press.

NRC. (2013). *Adapting to a changing world: Challenges and opportunities in undergraduate physics education*: National Academies Press.

Nyachwaya, J. M., Mohamed, A.-R., Roehrig, G. H., Wood, N. B., Kern, A. L., & Schneider, J. L. (2011). The development of an open-ended drawing tool: an alternative diagnostic tool for assessing students' understanding of the particulate nature of matter. *Chemistry Education Research and Practice, 12*(2), 121-132.

Orton, T., & Roper, T. (2000). Science and mathematics: A relationship in need of counselling? *Studies in Science Education, 35*, 123-154.

Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education, 25*(9), 1049-1079.

Özmen, H. (2004). Some student misconceptions in chemistry: A literature review of chemical bonding. *Journal of Science Education and Technology, 13*(2), 147-159.

Palmer, D. (1997). The effect of context on students' reasoning about forces. *International Journal of Science Education, 19*(6), 681-696.

Penuel, W. R., Fishman, B. J., Haugan Cheng, B., & Sabelli, N. (2011). Organizing research and development at the intersection of learning, implementation, and design. *Educational Researcher, 40*(7), 331-337.

Phillips, F. (2001). A research note on accounting students' epistemological beliefs, study strategies, and unstructured problem-solving performance. *Issues in Accounting Education, 16*(1), 21-39.

Pieters, J., & de Vries, B. (2007). Preface to the special issue. *Eductional Research and Evaluation, 3*(13), 199-202.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 63*(2), 167-199.

Porter, S. E., & Robinson, J. C. (2011). *Hermeneutics: An introduction to interpretive theory*: Wm. B. Eerdmans Publishing.

Posner, G. (2004). *Analyzing the curriculum* (3rd ed.). New York: McGraw-Hill.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211-227.

Pushkin, D. (1997). Fostering critical thinking in general chemistry labs via social constructivism. A development in pedagogy and curriculum. *Paper presented at the First International Conference of ESERA, Rome, Italy 1997*, 1-45.

Redish, E. F. (2003). *Teaching Physics with Physics Suite*. New York: John Wiley & Sons.

Redish, E. F., Saul, J. M., & Steinberg, R. N. (1997). On the effectiveness of active-engagement microcomputer-based laboratories. *American Journal of Physics, 65*(1), 45-54.

Reiner, M., Slotta, J. D., Chi, M. T. H., & Resnik, L. B. (2000). Naive physics reasoning: A commitment to substance-based conceptions. *Cognition and Instruction, 18*(1), 1-34.

Reiser, B. J. (2004). Scaffolding complex learning: The mechanisms of structuring and problematizing student work. *The Journal Of The Learning Sciences, 13*(3), 273-304.

Rivard, L. O. P. (1994). A review of writing to learn in science: Implications for practice and research. *Journal of Research In Science Teaching, 31*(9), 969-983.

Roblin, N. P., & McKenney, S. (2019). Classic Design of Curriculum Innovations: Investigation of Teacher Involvement in Research, Development, and Diffusion *Collaborative Curriculum Design for Sustainable Innovation and Teacher Learning* (pp. 19-34): Springer, Cham.

Rogoff, B. (1990). *Apprenticeship in Thinking: Cognitive Development in Social Context*: Oxford University Press.

Roth, W.-M., McGinn, M. K., & Bowen, G. M. (1998). How Prepared Are Preservice Teachers To Teach Scientific Inquiry? Levels of Performance in Scientific Representation Practices. *Journal of Science Teacher Education, 9*(1), 25-48.

Rowlands, S., Graham, T., Berry, J., & Mcwilliam, P. (2007). Conceptual change through the lens of Newtonian mechanics. *Science & Education, 16*(1), 21-42.

Sadanand, N., & Kess, J. (1990). Concepts in force and motion. *The Physics Teacher, 28*(8), 530-533.

Sadler, P. M., Sonnert, G., Coyle, H. P., Cook-Smith, N., & Miller, J. L. (2013). The influence of teachers' knowledge on student learning in middle school physical science classrooms. *American Educational Research Journal, 50*(5), 1020-1049.

Sandoval, W. A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education, 89*(4), 634-656.

Sargent, T. C. (2015). Professional learning communities and the diffusion of pedagogical innovation in the Chinese education system. *Comparative Education Review, 59*(1), 102-132.

Saul, J., & Redish, E. (1997). Final evaluation report for FIPSE grant# P116P50026: Evaluation of the Workshop Physics dissemination project. *University of Maryland*.

Savinainen, A., Mäkynen, A., Nieminen, P., & Viiri, J. (2017). The effect of using a visual representation tool in a teaching-learning sequence for teaching Newton's third law. *Research in Science Education, 47*(1), 119-135.

Savinainen, A., & Scott, P. (2002). The Force Concept Inventory: A Tool for Monitoring Student Learning. *Physics Education, 37*(1), 45-52.

Savinainen, A., Scott, P., & Viiri, J. (2005). Using a bridging representation and social interactions to foster conceptual change: Designing and evaluating an instructional sequence for Newton's third law. *Science Education, 89*(2), 175-195.

Schleiermacher, F., & Frank, M. (2004). *Hermeneutik und Kritik: mit einem Anhang sprachphilosophischer Texte Schleiermachers*: Suhrkamp.

Schommer-Aikins, M., Duell, O. K., & Barker, S. (2003). Epistemological beliefs across domains using Biglan's classification of academic disciplines. *Research in Higher Education, 44*(3), 347-366.

Schommer, M. (1990). Effects of beliefs about the nature of knowledge on comprehension. *Journal of Educational Psychology, 82*(3), 498.

Schwendimann, B. A. (2015). Concept maps as versatile tools to integrate complex ideas: From kindergarten to higher and professional education. *Knowledge Management & E-Learning: An International Journal, 7*(1), 73-99.

Scott, P. (1998). Teacher Talk and Meaning Making in Science Classrooms: a Vygotskian Analysis and Review. *Studies in Science Education, 32*(1), 45-80.

Scott, T. F., & Schumayer, D. (2018). Central distractors in force concept inventory data. *Physical Review Physics Education Research, 14*(1), 010106.

Scriven, M. (1994). Duties of the teacher. *Journal of personnel evaluation in education, 8*(2), 151-184.

Seidel, T., Prenzel, M., Duit, R., Euler, M., Geiser, H., Hoffmann, L., . . . Rimmele, R. (2002). Can everybody look to the front of the classroom please? *Patterns of instruction in physics classrooms and its implications for studentslearning*, 7-10.

Shaffer, P. S., & McDermott, L. C. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part II: design of instructional strategies. *American Journal of Physics, 60*(11), 1003-1013.

Shore, B. M. (2009). Giftedness Is Not What It Used to Be, School Is Not What It Used to Be, Their Future, and Why Psychologists in Education Should Care. *Canadian Journal of School Psychology, 25*(2), 151-169.

Shore, B. M., & Kanevsky, L. S. (1993). Thinking processes: Being and becoming gifted. *International handbook of research and development of giftedness and talent, 1*, 133-147.

Shymansky, J., Yore, L., D., T., B., T. R., A., H., D., W. L., . . . G., V. (1997). Examining the construction process: A study of changes in level 10 students' understanding of classical mechanics. *Journal of Research In Science Teaching, 34*(6), 571-593.

Slotta, J. D., & Chi, M. T. (2006). Helping students understand challenging topics in science through ontology training. *Cognition and Instruction, 24*(2), 261-289.

Smith, J. P., diSessa, A. A., & Roschelle, J. (1993). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *The Journal Of The Learning Sciences, 3*(2), 115-163.

Smithers, A., & Robinson, P. (2003). *Factors affecting teachers' decisions to leave the profession*. Retrieved from UK:

Sobhanzadeh, M., Kalman, C. S., & Thompson, R. I. (2017). Labatorials in introductory physics courses Labatorials in introductory physics courses.

Sokoloff, D. R., & Thornton, R. K. (1997). Using interactive lecture demonstrations to create an active learning environment. *The Physics Teacher, 35*(6), 340-347.

Soysa, C. K., Dunn, D. S., Dottolo, A. L., Burns-Glover, A. L., & Gurung, R. A. R. (2013). Orchestrating authorship: Teaching writing across the psychology curriculum. *Teaching of Psychology, 40*(2), 88-97.

Spatz, V., Hopf, M., Wilhelm, T., Waltner, C., & Wiesner, H. (2020). Introduction to Newtonian Mechanics via Two-Dimensional Dynamics--The Effects of a Newly Developed Content Structure on German Middle School Students. *European Journal of Science and Mathematics Education, 8*(2), 76-91.

Steinberg, R. N., & Sabella, M. S. (1997). Performance on multiple-choice diagnostics and complementary exam problems. *The Physics Teacher, 35*(3), 150-155.

Stewart, J., Griffin, H., & Stewart, G. (2007). Context sensitivity in the force concept inventory. *Physical Review Special Topics-Physics Education Research, 3*(1), 010102.

Stiles-Clarke, L., & MacLeod, K. (2018). Demystifying the scaffolding required for first-year physics student retention: contextualizing content and nurturing physics identity. *Canadian Journal of Physics, 96*(4), xxix-xxxvi.

Stoddart, T., Abrams, R., Gasper, E., & Canaday, D. (2000). Concept maps as assessment in science inquiry learning-a report of methodology. *International Journal of Science Education, 22*(12), 1221-1246.

Stosich, E. L., Bocala, C., & Forman, M. (2018). Building coherence for instructional improvement through professional development: A design-based implementation research study. *Educational Management Administration & Leadership, 46*(5), 864-880.

Taber, K. S., & García-Franco, A. (2010). Learning processes in chemistry: Drawing upon cognitive resources to learn about the particulate structure of matter. *The Journal Of The Learning Sciences, 19*(1), 99-142.

Treagust, D. F. (1988). Development and use of diagnostic tests to evaluate students' misconceptions in science. *International Journal of Science Education, 10*(2), 159-169.

Treagust, D. F. (1995). Diagnostic assessment of students' science knowledge. In S. M. Glynn, Duit, R. (Ed.), *Learning science in the schools: Research reforming practice* (pp. 327-346). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Trumper, R. (2003). The Physics Laboratory - A Historical Overview and Future Perspectives. *Science & Education : Contributions from History, Philosophy and Sociology of Science and Mathematics, 12*(7), 645-670.

Van Geert, P. (1998). A dynamic systems model of basic developmental mechanisms: Piaget, Vygotsky, and beyond. *Psychological Review, 105*(4), 634.

Van Zee, E. H., Iwasyk, M., Kurose, A., Simpson, D., & Wild, J. (2001). Student and teacher questioning during conversations about science. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 38*(2), 159-190.

van Zee, E. H., & Minstrell, J. (1997). Reflective discourse: Developing shared understandings in a physics classroom. *International Journal of Science Education, 19*(2), 209-228.

Vosniadou, S. (1994). Capturing and modelling the process of conceptual change. *Learning and Instruction, 4*(1), 45-69.

Vosniadou, S. (2001). Conceptual change research and the teaching of science. In H. Behrendt, Dahncke, H. , Duit, R. , Graeber, W. , Komorek, M. , Kross, A. (Ed.), *Research in Science Education - Past, Present, and Future* (pp. 177-188). Dordrecht,The Netherlands: Kluwer Academic Publishers.

Vosniadou, S. (2002). On the nature of naive physics *Reconsidering conceptual change: Issues in theory and practice* (pp. 61-76): Springer.

Vosniadou, S. (2008). Conceptual change research: An introduction. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. xiii-xxviii). New York: Routledge.

Vosniadou, S., Ioannides, C., Dimitrakopoulou, A., & Papademetriou, E. (2001). Designing learning environments to promote conceptual change in science. *Learning and Instruction, 11*(4-5), 381-419.

Vosniadou, S., Vamvakoussi, X., & Skopeliti, I. (2008). The framework theory approach to the problem of conceptual change. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 3-34). New York: Routledge.

Vosniadou, S., Vamvakoussi, X., & Skopeliti, I. (2008). The framework theory approach to the problem of conceptual change. *International handbook of research on conceptual change*, 3-34.

Vygotsky, L. (1978). Interaction between learning and development. *Readings on the development of children, 23*(3), 34-41.

Weaver, G. C. (1998). Strategies in K-12 Science Instruction To Promote Conceptual Change. *Science Education, 82*(4), 455-472.

Whitaker, R. J. (1983). An examination of student inconsistencies in their understanding of trajectory motion. In H. Helm, Novak, J. D. (Ed.), *Proceedings of the International Seminar "Misconceptions in Science and Mathematics"* (pp. 402-406). Ithaca, N. Y.: Cornell University.

White, B. Y., & Frederiksen, J. R. (2009). Inquiry, Modeling, and Metacognition: Making Science Accessible to All Students. http://dx.doi.org/10.1207/s1532690xci1601_2.

Wieman, C. (2015). Comparative cognitive task analyses of experimental science and instructional laboratory courses. *The Physics Teacher, 53*(6), 349-351.

Wieman, C., & Holmes, N. (2015). Measuring the impact of an instructional laboratory on the learning of introductory physics. *American Journal of Physics, 83*(11), 972-978.

Wilcox, B. R., & Lewandowski, H. (2016). Open-ended versus guided laboratory activities: Impact on students' beliefs about experimental physics. *Physical Review Physics Education Research, 12*(2), 020132.

Wilson, J. M., & Redish, E. F. (1992). The comprehensive unified physics learning environment: Part I. Background and system operation. *Computers in Physics, 6*(2), 202-209.

Wilson, J. M., Redish, E. F., & Donnelly, D. (1992). The comprehensive unified physics learning environment: part II. The basis for integrated studies. *Computers in Physics, 6*(3), 282-286.

Wilson, S. M. (2011). *Effective STEM teacher preparation, induction, and professional development.* Paper presented at the NRC Workshop on Highly Successful STEM Schools or Programs.

Windschitl, M., Thompson, J., Braaten, M., & Stroupe, D. (2012). Proposing a core set of instructional practices and tools for teachers of science. *Science Education, 96*(5), 878-903.

Won, M., Krabbe, H., Ley, S. L., Treagust, D. F., & Fischer, H. E. (2017). Science teachers' use of a concept map marking guide as a formative assessment tool for the concept of energy. *Educational Assessment, 22*(2), 95-110.

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of child psychology and psychiatry, 17*(2), 89-100.

Yinger, R. J. (1980). A study of teacher planning. *The Elementary School Journal, 80*(3), 107-127.

Yore, L. D., & Treagust, D. F. (2006). Current Realities and Future Possibilities: Language and science literacy—empowering research and informing instruction. *International Journal of Science Education, 28*(2-3), 291-314.

Zeichner, K., Payne, K. A., & Brayko, K. (2015). Democratizing teacher education. *Journal of Teacher Education, 66*(2), 122-135.

Appendix A

5- Newton's Second Law

The acceleration of a body is directly proportional to the net external force exerted on this body

$$\sum \vec{F} = m\vec{a}$$

- The acceleration and the net force have the same orientation (the mass is always positive).
- If the net force is constant then the acceleration is also constant (assuming the mass of the body does not change), therefore the movement of the body will be a Uniformly Accelerated Rectilinear Motion (UARM). Note that there are cases where the mass changes like a rocket that burns fuel while moving upward. The burning of fuel reduces its mass, which would cause in increasing acceleration instead of a constant one.
- The acceleration is inversely proportional to the mass.
- The force causes a change in the velocity of the body. The acceleration is a description of that change.
- On the axes of a reference frame, the second law can be expressed without the vector notation, because in one dimension, the sign is sufficient to determine the orientation of a vector:

  <u>On the x-axis</u>: $\sum F_x = ma_x$ <u>On the y-axis</u>: $\sum F_y = ma_y$
- The interpretation of Newton's Second Law yields several conclusions previously discussed. The conclusions are summarized in the image below:
  - If the object is at rest, then its acceleration is zero, so the net force is also zero (at rest → a=0 → net force is zero), which gives the principle of equilibrium, which states that if a boy is at rest then the sum of all external forces acting on the body is zero.

    $$\sum \vec{F} = \vec{0}$$

    At rest

    Or

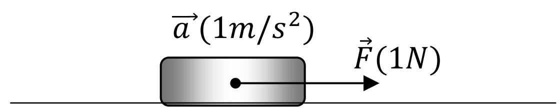
    URM
  - If the resultant of the forces is zero, then the acceleration is zero. This can happen in two cases: the object is at rest or the object has a Uniform Rectilinear Motion (URM). This conclusion is a reminder of Newton's First Law, which can be interpreted as: If no net force acts on a body, if the

body is at rest then it will remain at rest, if the body is in motion then its motion is a URM (constant velocity).

- Consider the arrow from the URM to the Zero net force. This arrow means that if the motion is uniform rectilinear (non-zero constant velocity) then the resultant force is zero. This means that a body can be in motion without any force on it (provided the motion is an URM). As seen in Newton's first law, this conclusion contradicts an idea that dominated science for centuries; this idea is that a force is needed to maintain motion.

Note -1:

A Newton (the unit of force in the SI) is defined as the force needed to give a mass of 1kg, an acceleration of $1m/s^2$.



When substituting the values above, of the net force, the mass and the acceleration, in the equation of Newton's Second Law we obtain $1N = 1kg.1m/s^2$ and this gives that $1N/kg = 1m/s^2$. In conclusion, the units N/kg and m/s2 are equivalent (same function). The gravitational field of 9.8N/kg on the surface of the Earth causes an acceleration of $9.8m/s^2$.

Note -2:

Newton's second law is a considered as a link, or a bridge, between dynamics and kinematics.

$$\underbrace{\sum \vec{F}}_{\text{Dynamics}} = \underbrace{m\vec{a}}_{\text{Kinematics}}$$

The left side of the equation above is that of dynamics, where we find the sum of the external forces (the cause of motion). The right side is that of kinematics, where we find is the acceleration (a description of the motion). The second law is not the only law that shows this link between kinematics and dynamics (between the cause and the consequence). Other laws have similar properties, for example:

Ohm's law : U=RI (seen in secondary 4)

Hooke's law : T= KΔl (to be seen in secondary 5)

Appendix B

Labatorial-5

Dynamics- Newton's Second Law

Names:	Grade:

Learning goals	Preparation	Material
Explore Newton's second law.	Read the course material on Newton's second law.	Fan cart, rope, ball, different masses (erasers would do). Sugar (or salt or sand) chronometer (or cell phone, tablet, computer), balance.

Activity 1: Let it go.

<u>20-30 min.</u> Place the fan cart on the ground (not on a table) turn it on and let it go (stop it before it hits a wall). In the space below draw a force diagram of the cart during its motion. The diagram should show the net force and the acceleration (vector) of the cart. Sketch a position-time, velocity-time and acceleration time graphs of the cart.

Add an extra mass to the cart, by adding a couple of erasers, such that they won't fall during its motion. Put the cart on the ground, start it and let it go. On the graphs of the previous part, use another colour to draw the curves corresponding to the motion of the cart with the larger mass. Use the space below to describe the motion of the cart in the best possible way (qualitatively and quantitatively), before and after increasing its mass. A ruler and a chronometer might be useful.

Use the motion of the cart, in both cases, to determine the force pushing it (developed by the fan)?

Stop

Checkpoint………………………………
Have your instructor check your results before you move on to the next part.

Activity 2: Rebound

20-30 min. Put the fan cart on the ground, turn it on and hold it to keep it from moving. Assuming that if you remove your hand the cart will move forward, push the cart backwards with your hand. The cart will travel backward a certain distance away from your hand then it will cease moving backwards and then it will move forward. In the space below draw a velocity-time graph and an acceleration-time graph of the cart from the moment it was at rest (held by your hand) until the moment it returns to the spot it was pushed from. Locate on the graphs the instants when you started pushing, when you stopped pushing, at the turning point and when it returned to its starting point. You are asked to use the same time scale in both graphs to enable comparison.

In the space below, draw a free body diagram of the cart (1) when at rest (held by your hand), (2) while pushing it backward, (3) after the push while the cart is moving backward, (4) when it ceases to move backwards and before moving forward and (5) while moving forward. For each diagram draw the resultant force and the acceleration.

Discuss with your teammates the orientation of the resultant force and that of the acceleration for each of the 5 situations. Does the 4th situation make sense to you? Comment.

Checkpoint……………………………………
Have your instructor check your results before you move on to the next part.

Activity 3: Catapult

20-30 min Throw the ball vertically upward. It will reach a maximum height and then it will drop back down to your hand. In the space below, draw a free body diagram of the ball (1) when at rest held by your hand, (2) while pushing it upward, (3) after the push while the ball is moving upward, (4) when it ceases to move upwards before moving downwards and (5) while moving downward. For each diagram draw the resultant force and the acceleration.

Discuss with your teammates the orientation of the resultant force and that of the acceleration for each of the 5 situations. Does the 4th situation make sense to you? Comment.

____

____

____

____

____

____

____

Free Fall is defined as the motion of a body when the only force acting on it is its weight. In real life (under normal conditions or circumstances), in order to consider that a falling body is in a free fall, the effect of the air on the body must be neglected. Let's consider cases 3 and 5 of the previous part while assuming that air resistance is neglected. In the space below draw a free body diagram of both cases, in the absence of air resistance while specifying the resultant force and the acceleration.

Describe the motion of the ball in both cases. A proper description requires trajectory, velocity, acceleration… and other important information.

Is situation 4 of the previous part different form situations 3 and 5? If yes, in what way?

Checkpoint………………………………
Have your instructor check your results before you move on to the next part.

Activity 4: Challenge

<u>15-20 min</u>. In the first activity you found a way to determine the magnitude of the force of the fan propelling the cart. Another way to find the magnitude of that force is to balance it with a known force. Brainstorm as a team to find a way to balance the force of the fan with a known force and use it to find the magnitude of the propelling force. Compare the magnitude of the force to the one obtained earlier (in the first activity). In the space below describe the experimental set up that enabled you to find the propelling force. Give all necessary details (diagrams, measurements….) and justifications (concepts, laws, approximations….) that enabled you to complete this task.

Stop

Make sure that your workstation is tidy. Follow your instructor's indications regarding the equipment used in this Labatorial.

The Concept Map

Name:	Class:	Date:

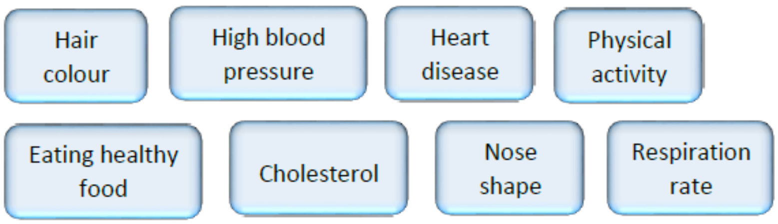
Dear student,

You are asked to complete a concept map on the relation between the content of the boxes below. To help you in this task, an example is given on the backside of this page. The example shows what a concept map looks like. Examine the given example before proceeding to your task. Please note that a concept map is not a collection of arrows between boxes. Each arrow must carry a label describing the connection between the boxes (see example). You may use colors to better assign labels to arrows. Please note that you don't have to use all the boxes and that you may complete this task using Word. All you have to do is to move the boxes as you wish and copy/paste labeled arrows from the example and then change the labels to your convenience.

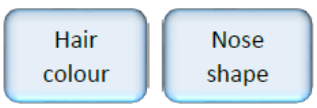
Rectilinear trajectory	Velocity changing at a constant rate	Body subjected to a force	Constant acceleration	Changing acceleration		
Zero velocity (at rest)	Body exerting a force	Constant velocity	Changing velocity	Parabolic trajectory	Force	

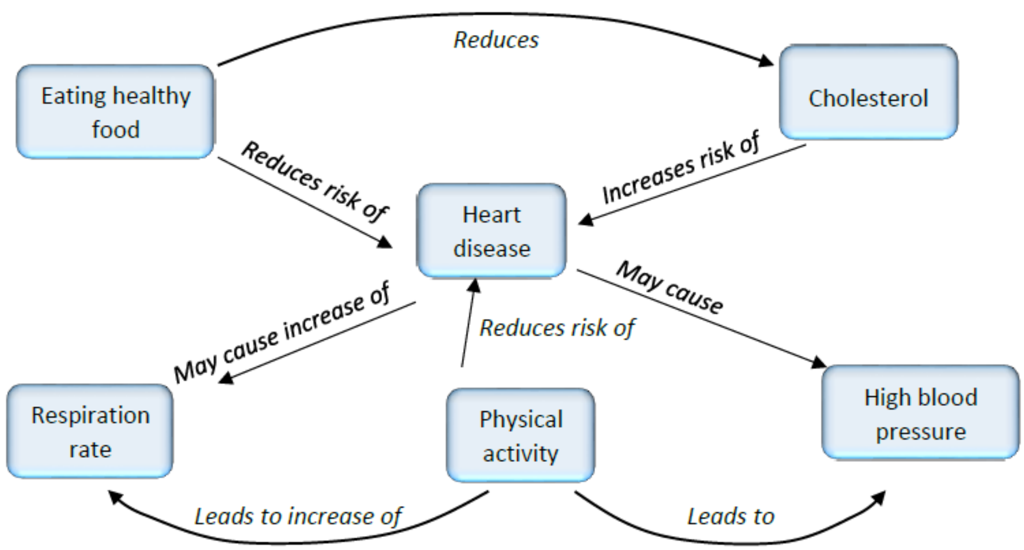
__Example:__

These are the given block to connect with labeled arrows



Below are the connections made between the blocks. Note that two blocks were not used.





Appendix C

Invitation to participate in a research study

Title: Labatorials and Reflective writing for a better understanding of dynamics in high school

Dear Student,
Dear Parent/Guardian

Students are being asked to participate in a research study aimed at investigating the impact of Reflective Writing and Labatorials on students' knowledge of scientific concepts. Reflective Writing is a process during which students are asked to write, in an informal manner, about their ideas and attitudes regarding science concepts and how they relate to one another. Reflective Writing promotes a better understanding of scientific concepts. Labatorials are worksheets that engage students working in a science lab. Labatorials require students to work through concepts that have been identified by research to be particularly difficult. Some require students to perform science experiments and answer the tutorial questions based on their observations. Their Reflective Writings and Labatorials are analyzed and compared to their attitudes and opinions toward the subject. These attitudes are probed by interviews and standardized tools (tests, concept maps) prior to the Reflective Writing and Labatorials exercises and following those exercises. All students are required to complete the described tasks as a part of their regular course work. If for any reason the student (or parent/guardian) does not wish to take part in this study, they are required to complete the provided opt-out form. Kindly be advised that even if a student opts out of the study, they would still be required to complete the tasks (Labatorials, Reflective Writing, concept maps…) as a part of their regular course work only their results will not be considered in the study.

The students' participation in the study will be invaluable in this process and might require them to take part in an interview that will focus on their attitudes and opinions toward Reflective Writing, Labatorials and scientific concepts. The interview will require a maximum of one hour of the student's time and will take place at the school under the supervision of the school's administration. If a student volunteers and is selected to be interviewed, a consent form (provided) signed by both the student and parent/guardian will be required. The student is under no obligation to volunteer to be interviewed. From the pool of students who will volunteer to be interviewed, a certain number of students will be selected for the interviews. Only those selected students will be required to provide the duly signed consent forms

Should you be interested in this study, we will be glad to share its results with you at its conclusion. To know more about Reflective Writing and how they positively affecting students' views and skills in learning kindly visit: http://reflectivewriting.concordia.ca/

Principal Investigator:
Joseph El-Helou
Graduate student, Department of Physics, Concordia University

Research Supervisor:
Dr. Calvin Kalman
Professor Department of Physics, Concordia University

Purpose of the Study:

The goal of the study is to investigate how Reflective Writing and Labatorials impacts the students' knowledge of scientific concepts.

Description of the Study:

The participants in the study will be asked to undertake Reflective Writing and Labatorials tasks and take part in two 20-30 minute long interviews. The interviews will take place in school, outside class time, under the supervision of the schools administration.

What is Experimental in this Study?

None of the interview questions used in this study are experimental in nature. The only experimental aspect of this study is the gathering of information for the purpose of analysis.

Risks or Discomforts:

Although the researchers are not aware of any apparent risks in the study, we understand that you might feel uncomfortable answering all the questions during the interview. Should this situation arise, please discontinue answering the questions either temporarily or permanently and get in touch with your High school principal as soon as possible.

Benefits of the Study:

We expect students will benefit from participation in the study since participating in the study will help participants reflect on their own learning and become aware of their personal science-related ideas. We hope that it will enhance students' science study skills and motivation to study science.

Confidentiality:

All the data collected in the study will be strictly confidential and nobody except for the researchers will have access to it. During the study all the data will be stored electronically on a password protected computer on a secure Concordia University server. The data will be erased and destroyed in five years after the completion of the study. The confidentiality will be maintained during the publication of the results of the study: no names or any other personal information will be included in the publications.

Voluntary Nature of Participation:

Participation in this study is voluntary. The student's choice of whether or not to participate will not influence his or her future relations with the Department of Physics at Concordia University or with his or her science teacher. If the student decides to participate, he or she is free to withdraw his or her consent and to stop his or her participation at any time without penalty. At any particular point in the study, the student may refuse to answer any particular question or stop his or her participation altogether.

Questions about the Study:

If you have any questions about the research now, please ask Joseph El-Helou, the Principal Investigator of the study (contact info on Page 2). If you have questions later about the research, you may contact Dr. Calvin Kalman (contact info on page 2).

Sincerely,
Joseph El-Helou

Opt-out of the study

This is to state that I do not agree to participate in a program of research being conducted by Joseph El-Helou, graduate student at the Physics Department of Concordia University.

I am aware that even though I will not be considered as a participant I would still complete the tasks related to the study (Labatorials, Reflective Writing and Concept Maps) required by my teacher at my school as a part of the regular course work. I understand that my results to these tasks will not be included in this study.

I HAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND THIS AGREEMENT.

Student's name: ____________________________ Class: ___________

Student's signature: ____________________________ Date: ___/___/_______

Parent/Guardian's name: ____________________________

Parent/Guardian's signature: ____________________________ Date: ___/___/_______

CONSENT AGREEMENT

This is to state that I agree to participate in a program of research being conducted by Joseph El-Helou, graduate student at the Physics Department of Concordia University

A. Purpose

I have been informed that the purpose of the research is to evaluate the influence of Reflective Writing and Labatorials on the students' understanding of scientific concepts.

B. Procedures

Students will participate in an interview about how they use Reflective Writing and Labatorials to better understand scientific concepts.

C. Conditions of Participation

- I understand that I am free to withdraw my consent and discontinue my participation at any time without negative consequences.
- I understand that my participation in this study is confidential (my identity will not be disclosed in any papers published or privately circulated that arise from this study.)
- I understand that the data from this study may be published.
- I understand the purpose of this study and know that there is no hidden motive of which I have not been informed.

I HAVE CAREFULLY STUDIED THE ABOVE AND UNDERSTAND THIS AGREEMENT. I FREELY CONSENT AND AGREE TO PARTICIPATE IN THIS STUDY.

Student's name:	___________________________	Class:	___________
Student's signature:	___________________________	Date:	___/___/_______
Parent/Guardian's name:	___________________________		
Parent/Guardian's signature:	___________________________	Date:	___/___/_______

Appendix D

Interview Questions

Pre-interview

1- Do you agree to be interviewed about your experience with Labatorials and reflective writing in the physics course?
2- What do you expect to learn from the physics course?
3- How do you study for the Physics course?
Probe: You told me that you use … to study for this course. What other materials do you use in studying for this course?
Probe: Do you use your own reasoning, past experiences, what the teachers say, what you read in books?
4- Before the next question, let me first give you the definition of pre-understanding. You may already have some ideas about physical concepts, such as force, velocity, mass and so on. These ideas may come from your former educational experience, or from your experience of the real world. Let's call all those ideas in your mind before you entered this course your pre-understanding. How do you think this pre-understanding helps you?
Probe: Do you bring your pre-understanding into studying for this course?
5- What if what you read (or what teacher says) is not consistent with your pre-understanding? What do you do in this case?
6- Based on your pre-understanding how do you describe the relationship between force and motion?
7- What do you expect from Labatorials in the physics course?
8- How do you expect Labatorials will help you in the studying process?
9- What do you expect from Reflective Writing in the physics course?
10- How do you expect Reflective Writing to help you to engage in your studying process?
11- Do you think that physics knowledge can change? How?
12- How do you evaluate yourself (objectively with respect to your classmates), in the physics course? Are you a strong, a medium or a weak student?

Post-interview

Important note: The student must not see the fan cart before its time. Ask the student not to discuss the interview questions with other students especially the other interviewee.

1- Do you agree to be interviewed about your experience with Labatorials and RW in the physics course?
2- Are your ideas about learning physics different now, compared to before you took this course?
3- Before the next question, let me first remind you of the definition of pre-understanding. You may already have some ideas about physical concepts, such as force, velocity, mass and so on. These ideas may come from your former educational experience, or from your experience of the real world. Let's call all those ideas in your mind before you entered this course your pre-understanding.
    - How do you think this pre-understanding helps you?
4- Did your work on Reflective Writing and Labatorials influence your pre-understanding or were they influenced by it? Can you give an example?
5- Did this course change your pre-understanding of certain ideas or concepts? Can you give an example?
6- In the first interview you were asked about the relationship between force and motion. What is your understanding of this relationship now? Is it still the same? What changed it?
7- Did your pre-understanding help you grasp the relationship between force and motion?
    - How did you go from your pre-understanding to your present ideas about force and motion?
8- Rate how each of the expressions (on the answer sheet) describes a force.

Poorly describes a force ← → Properly describes a force

Diminishes as the bodies move	1	2	3	4	5	6	7	8	9	10	11
Describes how a body acts on another.	1	2	3	4	5	6	7	8	9	10	11
Causes bodies to move.	1	2	3	4	5	6	7	8	9	10	11
Determines how the speed changes	1	2	3	4	5	6	7	8	9	10	11
Transferred to a body on contact	1	2	3	4	5	6	7	8	9	10	11

9- Rate how the activities (on the answer sheet) helped you shape your ideas about force and motion.

Not helpful ← → Very helpful

Reflective Writing	1	2	3	4	5	6	7	8	9	10	11
Class Discussions	1	2	3	4	5	6	7	8	9	10	11
Exercises/Problems	1	2	3	4	5	6	7	8	9	10	11
Tests/Exams	1	2	3	4	5	6	7	8	9	10	11
Concept map	1	2	3	4	5	6	7	8	9	10	11
Labatorials	1	2	3	4	5	6	7	8	9	10	11

<u>Experiment analysis (Fan Cart):</u>

The interviewer places the fan cart on the table and turns it on while keeping it from moving. The interviewer pushes the cart in the direction opposite to that dictated by the fan. The cart will move first in the direction it was pushed then it will move back toward the hand of the interviewer. The interviewer will ask: In this simple experiment there are forces and motion, can you please explain how they relate to one another?

Probes

- After the cart left the hand, what are the forces are acting it? Why does it slow down?
- What are the forces when it reaches its farthest point from the hand?
- Why does it return?
- What are the forces on its way back?
- What if the cart was pushed with the fan off, how will it move in this case and why?

10- Did Labatorials help you in examining your ideas or were they a waste of time? How? Did Labatorials help you reach your expectations of the course?

11- What would you change in Labatorials?

12- Did the RW activities help you meet your expectations of Labatorials? Would Labatorials be better, worse or the same without RW?

13- Do you think that physics knowledge can change? How?

14- How do you evaluate yourself (objectively with respect to your classmates), in the physics course? Are you a strong, a medium or a weak student?

<u>Drawing space</u>

Appendix E

Table 19: Post interviews transcript

	Questions	Student	Answers	Nb
1	Do you agree to be interviewed about your experience with Labatorials and reflective writing in the physics course?	MEM18	I do	1
		MET18	Yes I do	2
		FEU28	Yeah	3
		FES28	Yeah	4
		MFJ38	Oui	5
		FFL38	Oui	6
		FFC48	Oui	7
		FFK48	Oui	8
		MES19	Yes	9
		FEV19	Yes	10
		FFS49	Oui	11
		FFD49	Oui	12
2	Are your ideas about learning physics different now, compared to before you took this course?	MEM18	Yes, to a certain extent. Q: Can you tell me how they are different? Well, I came in with an already an idea on how things work around me and in the universe trying question what's going on, however, me taking this course is just allowing me to, like take a different perspective, more scientific perspective, and making my ideas, that are already there, clearer and putting them in better context in order to understand what is going on.	13
		MET18	They are, yeah. Q: different better, different worse, can you add something? The way we did it with the Labatorials was interesting compared to the standard lecture type of learning. We learned through examples and class discussions. We made experiments and our teacher could like help at checkpoints, he could help teach us on like, one on one level which really helped I think more than the general lecture type	14
		FEU28	I'm not sure because, it was a new experience for me, I think that everyone follows a traditional path to learning like, where the teacher teaches you, and like they'll teach you something in class and then you do exercises at home it's not like you do everything yourself and I think it was really refreshing experience, but personally, I think I still prefer the	15

			traditional way, because it was really hard for me to like figure everything out on my own and that's why teachers are here, they're here to support you and having everything learned by yourself, and it's a really new topic, I've never learned forces before, it was really hard, like in the beginning like, readings did help a bit, but it's kind of hard to imagine yourself when you have no experience with what you're learning, so readings kind of help and Labatorials kind of as well, kind of like, put it to light, like everything you read the light, but personally I enjoy like the teacher being there and teaching us everything beforehand, like I prefer that method better. Q: Okay, I have a question for you, I usually ask this at the end, but in your case I'm going to ask it now. How do you see yourself, with respect your classmates in the Physics course, are you a strong, weak or a medium student? I think that depends, I have my forces and my strengths, but there are things that I'm not as good as, it's like it really depends on the way I'm learning every subject. Like I usually start off kind of like slow, and the more I practice obviously the better I become I'm good I guess, like I usually, I put a lot of effort in understanding things, other students maybe they'll understand beforehand, maybe they have more intuition than me, but then they don't put the work so they lag behind. Q: Okay, but still, how do you evaluate yourself objectively with respect to your classmates in the Physics course, are you a strong weak or the medium student? When all is done, how do you see yourself, do you see yourself on the strong side, on the weak side, or somewhere in the middle? I think mostly on the strong side, but it ranges from medium to strong. Q: Ok another question, when you were doing Labatorials were you doing them in groups or alone. In groups Q: what about the discussions that went on in the groups, was that helpful to you? Were you leading or were you lead? I think we were all equally contributing but it was mainly going on between one of my friends and I, there was another person in the group but that person contributed a bit less than both of us, like my friend	

			and I we were mostly bouncing ideas off of each other, eventually do like, real life examples.	
		FES28	Yes because it was like very Interactive, what we were doing and before we did like less Interactive things, and it was good like to get together in groups and actually share ideas because I have like trouble understanding physics sometimes, so like to have other people to help me, it just helped. Q: When you say get together in groups, you're talking here about Labatorials right? Yes Labatorials.	16
		MFJ38	Différentes non, les apprentissages j'ai toujours vu pareil, c'est pas différent, c'est juste que maintenant, la physique je sais, je comprends les concepts et toute qu'est-ce que ça comprend, avant c'était pareil mais je connaissais beaucoup moins parce que je n'avais jamais eu de cours. Q : Oui mais par exemple, avant d'apprendre la physique est-ce que tu pensais que, par exemple que, pour étudier la physique il faut que je fasse un deux trois quatre cinq, et en faisant le cours tu as découvert, qu'il faut pas que je fais ça il faut plus que je fasse… Bien sûr, j'ai appris qu'il faut plus étudier des formules, je savais pas trop comment fonctionnait la physique, j'ai appris que c'est beaucoup avec des formules qu'on utilise pour qu'on met des données dedans pour donner un résultat, j'ai appris que c'est pas mal grâce qu'avec des formules qu'on obtient des réponses.	17
		FFL38	J'ai toujours cru que la physique était une matière qui change tout le temps et je le crois encore maintenant.	18
		FFC48	Oui, avant je pensais qu'étudier la physique c'était beaucoup plus, beaucoup d'exercices surtout mathématiques, maintenant c'est beaucoup plus un travail d'analyse, apprendre et d'autres aspects que juste les maths et les calculs.	19
		FFK48	Non, je ne pense pas vraiment, je pense que ça a été plus facile que je pensais. Q : Ah oui? Oui tout le monde avant le cours était comme, la physique ça va te tuer, comme tu vas mourir, c'est la plus difficile que tu vas jamais faire, mais après cette année j'étais comme. Q : C'était pas si pire que ça. Oui	20

		MES19	I think a little bit, because when we were doing the press review writings about the laws it forces you to write about something that you are not necessarily comfortable with. This kinda pushed me to understand This kinda pushed me to understand the topics more and gave me broader vocabulary in terms of physics. Q: here you are talking about the RW? Yes	21
		FEV19	I would say so, yes. Q: So do you think they are different? Like before taking this course in general, yeah. Do you ant me to elaborate? Q: Yeah, like how they are different? At the beginning I was like, like last year for example or before taking this course I didn't really have much of an understanding of physics in general, so I would say that now I have more, like this specific study was about forces, and I just didn't really know how it worked, I didn't, for example like an object, like at rest could have a bunch of forces applied on it, like I didn't really have any understanding.	22
		FFS49	Elles sont restées les mêmes. Q : des idées comme quoi par exemple? Comment on apprend la physique? Q : Oui Donc premièrement sur les exercices, je me souviens que plus on en fait, plus on a des différentes situations plus habiles, là c'est plus les lois de Newton qu'on, mais vraiment plus qu'on voit des situations comme dans les Labotoriels, plus on est familiers avec ces lois.	23
		FFD49	C'est sure que ça met de manière plus précise ce que je pensais avant ça, mais la manière que ça a été amené en classe j'ai trouvé que ca a été plus intéressant et j'ai eu l'impression que ca poussait vraiment plus à la réflexion personnelle que à l'imposition de matière Q : Que est ce que tu es entrain de dire? C'était quoi tes idée sur l'apprentissage de la physique? Apprendre la physique c'était plus d'assimiler des formules de les rendre puis de livrer la matière pendant l'examen mais maintenant c'est plus, c'est d'être devant la matière puis de réfléchir par rapport à elle tout en livrant la matière mais en la comprenant mieux	24

3	Before the next question, let me first remind you of the definition of pre-understanding. You may already have some ideas about physical concepts, such as force, velocity, mass and so on. These ideas may come from your former educational experience, or from your experience of the real world. Let's call all those ideas in your mind before you entered this course your pre-understanding.	MEM18	Sometimes it does, sometimes it doesn't, it does in the sense that like, I mentioned I have a critique of everything that I perceive because I know I'm incapable of , actually understanding everything that is going on, in the way that is actually going on, it gives me some sort of basis to build further knowledge however some of this base is weak and it's not full of actual understanding of how things are going, and which hinder me from understanding things moving forward such as when we talked about forces, yes I understand theoretically the idea of anything you apply force on, its applying the exact same force back on you, but I like, it took me a little while to be able to, like see it, actually see it other than theoretically, actually be able to witness it and identify it and work by it.	25
		MET18	I think it helps, like give like context to everything and like, I had some knowledge before taking the course, so this really helped solidify my previous knowledge, and it also helped expel any miss… yeah, if I thought that something wasn't corrected, it helped me get rid of that.	26
		FEU28	Well, I don't know if this is bad, but I'm not a very physics person, when I look around in the world I don't care about what physics goes on there. I just live my life and I think about the things that I need, the things that are important to me, like obviously physics exist around us, and it's around us right now, but I don't really pay attention to it, like if someone pushes me in soccer, like if someone bumps into me in the hallways, like I won't think what kind of impact did that…. I won't think that my pre-understanding of physics really changes anything to what I learned because it doesn't apply to my real life.	27
		FES28	I would say like yes, I think, because just like, I knew what in general, and then when I did like the reflective writing part. When I was doing the reflective writing I could relate more to those subjects, and it helped me like to understand some of Newton's Laws, so knowing like those concepts before, helped to like interpret the material that we learn.	28
		MFJ38	Je pense qu'elle m'aide dans la compréhension dans la mise en situation réelle des concepts. Mettons qu'on parle d'une force, comme n'importe qu'elle qu'on a appris en physique, je fais faire ah on apprend quelque chose, ah oui c'est vrai ça explique pourquoi mettons	29

			une situation dans la vraie vie qui s'est passée. Donc ça me permet d'associer un concept qui est théorique, comme une formule, qui est juste avec mettons, la force puis la gravité, ça me permet de prendre cette formule-là puis de me faire un concept et la visualiser dans un contexte réel, comme dans la vraie vie. Ça me permet de, pas de remettre en question, mais de changer ta perception, comme ça tu comprends mieux quand tu fais un exemple ou exercice. Au lieu de juste voir les données, tu peux penser comme ah oui, et vraiment visualiser l'événement.	
		FFL38	Elle permettait de mettre des points plus précis sur un sujet, après ça je pouvais rajouter de l'information sur ce j'apprenais dans le cours. Donc j'avais une idée de départ et je la modifiais au fur et à mesure que j'apprenais quelque chose au lieu de partir de rein du tout j'avais une base.	30
		FFC48	Je pense que ça aide, dans le fond c'est, quand on a le cours on peut faire des liens plus facilement avec qu'est-ce qu'on connaissait déjà. Donc ça aide à faire des liens puis à comprendre mieux le cours par la suite.	31
		FFK48	Ça nous donne une base, sur laquelle nous baser genre, parce que si on arrive sachant rien c'est comme on a plus de chemin à faire. Je pense que des fois ça peu comme pas nous aider parce que on doit défaire des bouts, Mais c'est ça, oui.	32
		MES19	I think it did help me a lot, especially this year in terms of this unit, I feel like I have a pretty good preunderstanding of some of the laws of physics especially since when we ar like doing some of the topics and I remember speaking to my dad about some of the things when I was younger, and he would explain certain that we were going over now, and in my mind when I was younger it didn't mean that much to me, but now, as we were going through it, I was grateful that I had that understanding for the topics	33
		FEV19	I think that just like past experiences because you can connect, because physics is just like a physical with lots of real life examples, like in the course when we are looking at the laws and stuff and how we were talking about real life situations and like our reflection, how these past experiences can, like help you understand whats going on and like you can look at videos for examples, the teacher was showing us a	34

			bunch of videos how, like the applications of physics like in real life. Q: So you are saying that it helps knowing stuff before taking the physics course? Yeah, well I didn't know that much about physics before taking the course, like I lived my life, like for different things all around us in general. Q: would you say that the stuff you knew before, were they like a positive impact on the physics course or a negative impact on the physics course? Like what I already knew, helped me or confused me? I would say that it more confused me because, because like what I thought I knew wasn't actually true. Like I was never actually taught.	
		FFS49	Ça nous permet d'apprivoiser ce qu'on va avoir, on a des exemples de nos vies personnelles des choses auxquelles on puisse s'identifier forcement ça va nous aider à la compréhension, pouvoir mettre des exemples de notre vie quotidienne, des exemples de la physique.	35
		FFD49	Ça nous donne une opinion avant de rentrer dans le cours qui peut être cassée ou qui peut être gardée qui peut être utilisée de différentes manières, il ne faut juste pas trop y tenir, parce que ça change vite	36
				37
				38
				39
				40
	Probe: How do you think this pre-understanding helps you?	MEM18		41
		MET18		42
		FEU28		43
		FES28		44
		MFJ38		45
		FFL38		46
		FFC48		47
		FFK48		48
		MES19		49
		FEV19		50
		FFS49		51
		FFD49		52
				53
				54
				55
				56

4	Did your work on Reflective Writing and Labatorials influence your pre-understanding or were they influenced by it? Can you give an example?	MEM18	They were definitely influenced by it, by my preunderstanding, when I wrote those reflection and I had this some sort of definition, review paper thing, and I had to reflect on it, it was more influenced by my understanding previously, by my preunderstanding if you want to call it that, because, my preunderstanding, everything like that I understood I thought that it was correct, this is why I was working by it, however I had some sort of doubt in my mind, which is what I put on the paper when I'm writing my reflections, and because it was only theoretical, on the paper, I was able to visualize what I was being taught or what I was reflecting on, or what was demanded from me, it like, it was fully influenced by what I had before, whatever ideas I had before, before I started this course.	57
		MET18	I think they were influenced by it, when I was reading the text like, I had often made connections to what I have previously learned, and just like, outside world examples, and by doing reflective writing or Labatorials Q: Did that also change your pre-understanding or your pre-understanding changed it? I think it did ,yeah, it helped modify it into what is like, actually true, if I didn't know something, like I said before, if I didn't know something then it was expelled, and if I knew something, then it was really solidified through the examples and the writings.	58
		FEU28	Like obviously when I did the reflective writing there was a section where I had to relate it to real life, and that's where I started to think about it, how it was actually involved in everyday life. It was mainly like doing the Labatorials that impacted my pre-understanding and it was not my pre-understanding that impacted.	59
		FES28	I think that what I read I'm like very visual. Q: You said that you are a visual learner? Yes and I like hearing too though, so like the reading it was beneficial again. It helped a lot though. But I'm like usually a visual and hearing and it actually helped a lot to understand because if I didn't understand like, the writing then I would like ask someone about it. Q: but did your pre-understanding affect your reflective writing or did your reflective writing affect your understanding? Both had an impact on each other, because when I was writing my reflective writing I was able to interpret the	60

			subject more and related more to my pre-understanding, when using those Concepts. But then with pre-understanding I was able to grasp more from the reflective writing.	
		MFJ38	Comme j'ai mentionné précédemment, la précompréhension ça la aider pour surtout les ÉR quand on apprenait sur un sujet, une loi de Newton par exemple, après ça, je lisais comme les informations dans le document qu'on avait puis après ça pour écrire mon ÉR je pouvais mettre comme dans un exercice, mettre en situation la loi. Fait que ça me permettait d'avoir plus de facilité à écrire mon écriture parce que je me donnais des exemples de vie réelle qui s'appliquaient avec une formule fait que, prendre une formule de physique, puis la transformer dans un contexte réel. Q : Quand tu parles ici de contexte réel et de formule de physique, tu parles ici des Labotoriels et de l'ÉR? Oui Q : Donc tu es entrain de dire que ma précompréhension c'est le monde réel que je savais et les ÉR et les Labotoriels et ces formules ou ces connaissances en physique et ça t'a permis de créer un lien par exemple entre l'une …. Comme par exemple, quelque chose que je savais déjà : lâche un objet il va tomber par terre, la physique ça m'a permis d'apprendre que c'est parce que la gravité tombe, c'est un exemple de base, c'est pas pour la gravité, c'est pour dire, j'ai pu apprendre que c'est à cause de la gravité que la balle elle tombe par terre. C'est à cause de ça, parce que les deux s'attirent avec leurs masses. Donc ça m'a permis d'associer un évènement comme exemple pousser un frigidaire avec une pente ou n'importe quoi, avec une formule ou un concept.	61
		FFL38	C'est certain que quand je faisais une ÉR, je me posais des questions, ça me permettait de pousser plus loin ma précompréhension c'est-à-dire je commençais l'ÉR j'avais déjà la base de ce que je connaissais mais là en écrivant je me posais plus de questions sur ce que je connaissais donc ça me poussait à plus réfléchir. Donc avant d'entrer dans le cours j'avais déjà une précompréhension qui était plus avancée. Q : j'ai compris, la tu es entrain de donner un compliment à l'ÉR d'une façon parce que tu savais avant d'entrer au cours. Ok, mais est-ce que tu es	62

			entrain de nous dire que la précompréhension a affecté l'ÉR, ou bien que l'ÉR a affecté la précompréhension. L'ÉR a affecté ma précompréhension. Q : Est-ce que tu peux nous donner un exemple? Si tu peux penser à un exemple où tu avais quelque chose comme précompréhension, après ça l'ÉR t'a aidé à un peu modifier ça. On parlait de, vous savez quand on pousse un ballon dans l'espace mais que si on pousse ici, avec un certain angle, on va faire des ronds par l'arrière mais qui sont, mais si on le pousse ici sans angle on ne va pas nécessairement faire des ronds, si on poussa ça parfait là. Techniquement, quand j'ai fait l'ÉR, elle m'a fait réfléchir à ça. Pour moi si je pousse un ballon comme ça, avec ma tête j'aillais toujours être droite même s'il y a un angle ou non, mais j'ai commencé à rire et je me suis, voyons, je n'ai pas le même centre donc ça ne fonctionne pas, mais quand j'ai fait l'ÉR, j'ai un peu réalisé ça, je me posais la question dans mon ÉR et en cours après ça j'ai pu comme vérifié.	
		FFC48	Quand je faisais les Labotoriels ou l'ÉR, c'est sûre que en ayant une précompréhension déjà établie avant ça influençait comment je pensais dans les Labotoriels, puis vraiment le fait de discuter en équipe dans le Labotoriel parfois on était d'accord sur certain aspect parfois on n'était pas d'accord parce que il y a des gens qui voient les choses autrement, à cause de leur précompréhension à eux-mêmes, donc oui ça influençait notre analyse mais en même temps les Labotoriels nous ont fait poser des questions sur qu'est-ce que nous on savait déjà.	63
		FFK48	Je pense que la précompréhension a influencé les Labotoriels et les ÉR parce que, je pense que dans toutes les choses que tu vois dans la vie, c'est toujours influencées par ce que tu sais déjà, mais aussi je pense que une fois que ces choses sont faites comme l'ÉR et tout, quand tu comprends quelque chose d'une manière différente ça influence aussi la précompréhension. Je ne sais pas si je réponds à la question mais. Q : Oui, tu dis peut-être que ça va affecter la précompréhension dans le sens que ça va la changer peut-être. Oui Q : Ça va changer les choses que tu connaissais. Oui.	64

			Q : Est-ce que tu a un exemple en tête? Quelque chose que tu pensais qu'il était comme ça mais que les Labotoriels ou l'ÉR ont changé ou quelque chose dans le cours de physique. Moi je sais qu'avec l'ÉR ça m'a aidé à voir toutes mes idées et ma façon de penser, mais ce qui m'a vraiment aidé c'est comme parler des ÉR en classe. Parce que là, c'est comme tu peux comme cibler où t'a mal pensé. Alors moi comme j'avais pas vraiment compris, comme avec la deuxième loi de Newton comment ça s'annulait pas les deux forces. Q : La troisième loi de Newton. La troisième loi de Newton, oops, mais là quand on l'a discuté en classe, vous avez dit quelque chose qui a comme cloché, et moi j'étais comme ah j'ai compris.	
		MES19	I think, for what I knwe before in terms of thinking of like, motion, something we learned this year, motion being separated on the x and y axis and stuf like that and especially how that come into play when you are talking about the laws of inertia its like something that I had known when I was younger but learning about it now has given me a more broader understanding especially having to write about inertia and like for example the hockey puck sliding on ice when there is not a lot of friction nothing touches it, in a frictionless world it technically wont ever stop. Which is a concept like I've known about, but for some people its harder to understand but for me since I had that preunderstanding it just kinda clicked easier. Q: Do you play Hockey? I used to Q: because you chose that example Yeah, it's a relatable example.	65
		FEV19	I think that what I already knew influenced my RW. Q: Can you give an example? Like when the teacher really put an accent on us bringing examples from real life situations, like talked about sailing and activities like that so I tried to apply the concepts that I read about in the sheets to real life experience and not the other way around.	66
		FFS49	Moi je dirai que ma précompréhension a influencé les ER et les labotoriels. En faites, dès qu'il y a une confusion entre ce que je lisais, les lois de Newton par exemple, je lisais je voyais, qu'il y avait une idée contraire à ce que je croyais c'est là que je l'écrivais	67

			directement dans mes ER comme quoi là, je ne sais pas pourquoi ça fonctionne comme ça.	
		FFD49	J'imagine que c'est un mélange des deux parce que ce poussait vraiment, mettons les réflexions écrites c'était vraiment plus par rapport à la réfection personnelle que ce que nous on était capable de comprendre et ou est-ce que on avait besoin d'aide d'être éclaircie mais quand on regarde plus le côté des labotoriels c'était vraiment une compréhension commune on s'aidait puis on se disait, on comprenait la matière ensemble, puis avec l'aide du professeur, c'était toujours plus apprécié quand le prof était capable de mettre en avant sur quoi on devait focusser pour comprendre tout le reste. Q : mais la relation entre ça et la précompréhension? L'idée de justement cette précompréhension-là collective ça aidait justement à renforcer qu'est-ce qu'on avait déjà, ou de renter encore plus profonde dans que ce qu'on ne comprenait pas	68
				69
				70
				71
				72
5	Did this course change your pre-understanding of certain ideas or concepts? Can you give an example?	MEM18	For example, in a certain lab, if you let me describe it, we had this some sort of a something on a wheel which has a fan on it. Q: It's a fan cart Yes a fan cart, and how when you remove the plastic you expect it to move, but when you put it back, you expect it to move in the other direction, well that's what I did expect to happen, but it didn't, and all the ideas that I had before I initiated this lab came to some sort of a crash, or to some sort of a lag, I was intrigued and I was asking questions or to change this understanding, and in order to be able to predict the results of the next one, the next experiment, the next subsection of the overall Labatorial.	73
		MET18	When like learning Newton's Laws, you need like an action for a reaction, I think that's the third law, and there's like common misconceptions, that like I think we were talking about things that just like happen, but you need like a force to start acting on something, for the thing to start moving.	74
		FEU28	In my pre-understanding I did not really realize that it was an action-reaction thing or type of concept in forces, and reading the Labatorials, that was like the	75

			main idea the thing that stood out to me the most, like there's an action-reaction, you could do something, there's an impact here, but there's also an impact somewhere else. It's like a chain reaction everywhere around the world and that is what impacted me the most, I don't know, if I apply that to real life, there isn't always a chain reaction, like for instance I talk to somebody and there's a chain reaction after that. Before I didn't know about the concept of Action-Reaction but reading the Labatorials, it kind of like helped.	
		FES28	I didn't really take physics before so I wasn't, so I didn't understand that much, but it's more, not like that I thought of something differently after, but more like I learned new things, because I was really confused about physics. Q: It would be nice to have an example, something like I used to think that something was like that, but I discovered that it wasn't like that. I think the concept of inertia, that's an example, because before, I like I don't know why, but I never thought of it, it's not like my thoughts changed about the concept of inertia, but it's like a new thing and I liked it and it interests me.	76
		MFJ38	No c'est plus que je voyais quelque chose qui se passait, ça m'a juste expliqué pourquoi ça arrivait. Je n'ai pas d'exemple qui me vient en tête. Q : Tu as déjà donné un exemple. Dans la vie en général, on voit quelque chose qui se passe, on ne sait pas trop pourquoi, puis après avoir appris la physique ou le cours on se dit mais oui, c'est à cause de cette loi ou à cause de ceci. Q : ce que tu dis c'est que tu as appris quelque chose dans le cours qui t'a aidé à expliquer un phénomène, mais est-ce que tu pensais que quelque chose qui n'était pas bon, que le cours t'a aidé à le corriger? C'est n'est pas juste expliquer ce que tu vois. Tu as donné l'exemple de la balle qui tombe parfois on dit que, ah ok je pensais j'ai cru que par exemple c'est le soleil qui tourne autour de la terre, mais en faisant le cours j'ai appris que, non le soleil ne tourne pas autour de la terre. Est-ce que le cours t'a aidé à corriger quelque chose? Oui, exemple quand on lâche un objet sur le sol, ou n'importe quoi, je pensais que vu, exemple la masse de la terre était beaucoup plus grande, c'est juste	77

			l'objet qui allait descendre, ce n'est pas la terre qui bouge, parce que en théorie quand tu lâche un objet, nous on pense la terre va pas bouger mais techniquement quand on lâche un objet, l'objet se rapproche et la terre aussi, comme un peu, mais genre.	
		FFL38		78
		FFC48	Oui, c'est sûr. Q : Pouvez-vous donner un exemple? Quelque chose que tu connaissais dans ta précompréhension qui a changé. En ce moment je n'ai rien dans la tête.	79
		FFK48		80
		MES19		81
		FEV19		82
		FFS49	Oui, forcement, Q: est-ce que tu as un exemple? Oui par exemple, un vélo et une voiture qui se heurtent en face pour moi c'était évident que la voiture avait beaucoup plus de force sur le vélo alors que non c'est vraiment, l'effet qui est observé c'est due à la masse, mais la force est équivalente, de la voiture sur le vélo et du vélo sur la voiture.	83
		FFD49	Oui, ils ont été plus approfondie plus que changer Q : tu as un exemple? Les lois de Newton, C'est quelque chose que tout le monde comprend de très très loin on voit c'est quoi, on vit notre vie on pense c'est quoi l'inertie on pense c'est quoi un élan on comprend cette notion la mais on n'est jamais rentrer en détail on n'a jamais vraiment compris avec des forces c'était quoi, l'idée de ma précompréhension la bas c'était vraiment très basique et je m'y était jamais vraiment attardé sur le sujet personnellement l'idée du cours qui pousse plus loin et ça nous pousse nous a poser de bonnes questions pour qu'on soit capable de comprendre ça m'a vraiment aidé a bien assimiler la matière	84
				85
				86
				87
				88
6	In the first interview you were asked about the relationship between force and motion. What	MEM18	Most definitely my ideas have developed, however like the idea that I mentioned, it was a good time ago and I don't remember it, and probably this is a good thing, because it had some inaccuracy in it, and in this section I performed better than the previous sections that I had in the overall physics course, in the force	89

	is your understanding of this relationship now? Is it still the same? What changed it?		courses, then the force and motion course I've performed better because I actually personally witnessed my personal development, I don't remember what I said.	
		MET18	I learned that, when we were doing the free body diagrams that's like, the force is to be drawn independently from the motion and that motion is like only to be considered later, I'm not sure how to really explain it, but when we were doing the free body diagrams we were always drawing forces and, at the beginning we were like, it was like confusing to distinguish between like, the actual forces and the motion of the object. But after the Labatorials it was like more distinguishable, which was the motion and which was the force behind the motion.	90
		FEU28	I think that I still see the connection in a very standard way, like if you apply a force then motion can happen, that's the way I see it, I guess. If you apply a force you might create motion. Q: Might? Could you exert a force on a body and not create motion? Yeah, I mean like right now, if the weight of the table, ok if applied this, but not applied a big enough force, then no motion is created, it still remains. Q: ok so you can have a force without creating motion. Would the other way around work? I mean, can we have motion without a force? Yes, like if you have a hockey puck on the ice, you apply a force to it but then, because, you just applied a force at the beginning, have it like start but, no force is required to keep the motion along.	91
		FES28	I think that to be able to put an object in motion you need like an external force, to be put on that object. To be pushed by something or to be pulled. Q: So if an object is not moving and you want to move it you have to push it? By an external Force. Q: Did you think like that before you took the course or after you took the course? Was there any change about this notion of force and motion, before and after you took the course? Did you detect any change? Yeah before I took the course I didn't really think of the things I did and how it applies to physics. I didn't really think it was a big deal. But after, like now, when I'm playing sports I'm like woh external force.	92

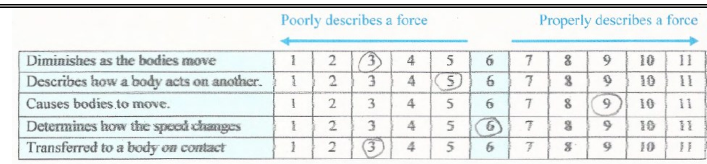
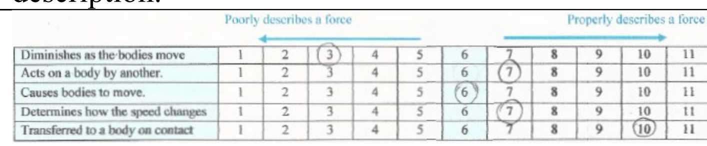
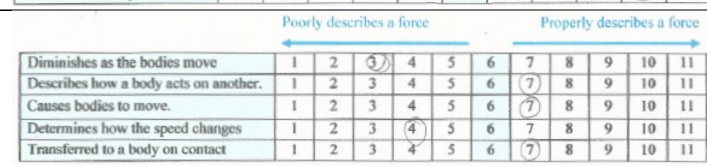
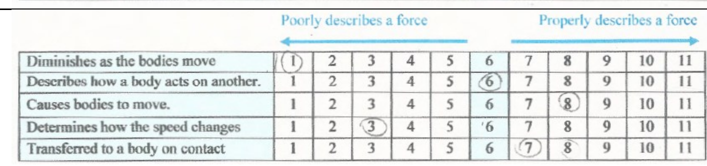
		MFJ38	Un mouvement un est créé tout le temps par une force, mais si non, que ce qui je croyais avant le cours? Q : Si tu t'en rappel ça, ça serait très bien. Mais je pense que ça n'a pas vraiment changé, parce que j'ai toujours dit que, une force qui cause un mouvement, ça n'a pas vraiment changé, j'ai juste appris comment, plus pousser la force ensemble et le mouvement ensemble les relations, mais si non je savais que c'était vraiment qu'une force qui crée un mouvement. Q : Tu dis que si j'ai une force sur un corps ça va mettre ce corps-là en mouvement. Est-ce qu'il est possible d'avoir un corps en mouvement sans qu'il y est une force? Sans une force? Q : Oui, est-ce qu'il est possible d'avoir un corps qui bouge sans qu'il y est une force sur ce corps? Oui, il me semble, si on est sur un sol qui n'a aucune friction, on donne une poussée, après ça on lâche le corps il va continuer à avancer mais il y a aucune force appliquée sur lui. Q : Est-ce que tu savais ça avant le cours? Non, mais dans l'espace oui, mais hors de l'espace, je ne me suis jamais dit, jamais pousser plus loin.	93
		FFL38	Avant je croyais que toujours un mouvement s'il avait une force constante qui est appliquée sur lui, mais la maintenant je comprends qu'il peut y avoir un élan avec l'inertie. Avant je pensais que juste un mouvement avait toujours lieu quand on le poussait et quand on est toujours en train de le pousser, mais après l'étude j'ai réalisé que le mouvement on peut le pousser, mais après ça, la force de l'inertie va faire en sorte qu'il continu même s'il n'y a plus de force qui est appliquée, techniquement la force de départ.	94
		FFC48	Avant je pense que je pensais que s'il y a une force, il y a absolument un mouvement. Mais maintenant, ce n'est pas s'il y a une force il y a nécessairement un mouvement. Q : Un exemple, comment tu peux avoir une force sans avoir un mouvement? Par exemple cette table en ce moment ici, elle n'est pas en mouvement, elle est au repos mais il y quand même une force normale une force du poids. Q : Et si j'inverse ça, est ce qu'on peut avoir un mouvement sans avoir une force? Oui.	95

			Q : Comment? Par exemple l'inertie, donc s'il y a une balle qui roule, elle ne subit pas ni le frottement ni rien, comme par exemple dans l'espace, il n'y a aucune force mais les particules sont quand même en mouvement continue. Q : Les particules? Les molécules, ou peu importe ce qu'il y a dans l'espace. Q : Planètes, astronautes. Exactement, planètes, astronautes ou des météorites. Q : Est-ce que tes idées de la force et du mouvement ont changé? Oui, Je vois la relation entre les deux maintenant, avant elle n'était pas claire. Je pensais qu'il y avait une relation entre les deux, mais je ne savais pas vraiment comment les mettre ensemble. Mais Maintenant c'est beaucoup plus clair.	
		FFK48	Je ne me rappelle plus ma première répons mais maintenant je pense que c'est plus comme, quand on parlait de comme sans frottement, comme quelque chose si c'est en mouvement va continuer à être en mouvement, puis ça change seulement avec une force qui est appliquée sur le corps, c'est comme ça que je le pense maintenant. Je ne sais pas si, je pense que c'était différent avant, car je n'ai jamais pensé à ça. Q : Ça c'est un ajout tu dis, c'est un ajout que tu ne connaissais pas. Généralement, il me semble que ce que tu as dit avant, tu as dit, la force peut causer un mouvement. Je dirais la même chose maintenant, si quelque chose est au repos et tu exerces une force là-dessus ça va être en mouvement. Sans frottement ça va rester en mouvement.	96
		MES19	So from what I understand, in order to have motion that means that there has to be some sort of an initial force and once that force has stopped being applied, or is it like a constant force not an accelerating, or constantly getting greater, just like being the amount of friction that is there and that is all the your force is doing, the object is basically moving on its own. Like for me on thing that I found cool was like pushing a box on the floor this is one of the examples we did eventually once I pass a certain point of pushing the box, the only thing I'm pushing is I'm fighting the box's restriction by friction but the box is technically moving with the inertia I given it at the beginning. So	97

			that was an interesting way for me to think of it especially since I always just thought of it, like just, pushing a box.	
		FEV19	I think that there is a certain connection between the two, you don't need force… actually wait no, this is hard. Like what we learned, like force needs to be applied to like to bring an object from rest to motion or from motion to rest, like to change the state, it's like the inertia that we read about. Like a force needs to be applied like to change the inertia, like change the speed of the object.	98
		FFS49	J'ai oublié ce que j'ai dit dans la première entrevue. Q : Ce n'est pas grave Ce n'est pas ma compréhension, je savais déjà ce que c'est un mouvement et une force, mais je fais plus les liens entre les deux maintenant vous-voyez? Par exemple, je sais que, un mouvement n'est pas forcement causé… non non désolé, un mouvement peut être présent sans la présence de force. Ou au contraire la force peut modifier un mouvement et ce n'est pas forcement, par exemple un objet a un mouvement, que cela veut dire automatiquement que la force va avoir la même orientation, c'est plus les liens entre les deux que j'ai mieux compris, mais la définition en tant que tel je l'avais déjà.	99
		FFD49	C'est clair que ça a probablement changé car je comprends mieux les notions maintenant mais, c'est sure que les liens sont très complexes c'est difficile d'en parler comme ça mais c'est claire que ça a totalement change dans les sens que, même si je disais la même chose que j'ai dit la dernière fois je le dirais de manière beaucoup plus approfondie et avec un plus gros bagage	100
				101
				102
				103
				104
7	Did your pre-understanding help you grasp the relationship between force and motion?	MEM18	Definitely, like I was familiar with the, for example laws of, like newton's three laws, or the one which I learned about, I was familiar with them, but they were not clarified enough. But I had some sort of basis, theoretical basis of understanding to be able to apply it and help myself get out of misunderstanding that I was at.	105
		MET18		106

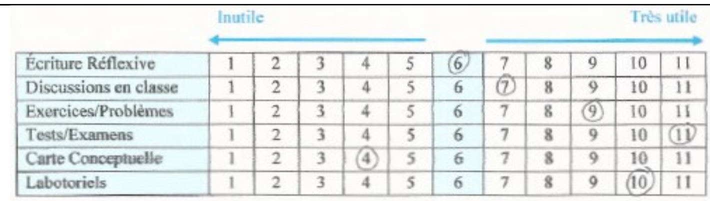
		FEU28	I think yes, because it allowed me to understand a part of what the relationship between force and motion is but it didn't help me understand it completely, but it did help me create like a foundation that I could build on after when reading Labatorials.	107
		FES28	Yeah because what we learned before with the position time, velocity time and acceleration time graphs we had to draw like those graphs and then we have to, and when we actually did them in the Labatorials, like hands-on, like it helps you to understand and you could relate it back to your pre-understanding.	108
		MFJ38	Je peux répéter la même chose que j'ai dit avant.	109
		FFL38	Non, ma précompréhension n'était pas vraiment bonne. Je ne comprenais pas, ma précompréhension était vraiment comme un nuage, ce n'était pas précis, j'étais un peu comme perdue.	110
		FFC48	Oui ça aussi, surtout avec les ÉR en les mettant sur papier, ça m'a aidé à comprendre la vraie matière par la suite. Q : Donc tu dis qu'avec L'ÉR ça t'a aidé. Oui.	111
		FFK48	Oui, mais parce que c'est logique right? Tu pousses quelque chose, puis ça bouge, c'est comme je le savais déjà.	112
		MES19	I think so, Especially, like things with space or with the hockey puck example, like once you give that puck motion it's going to keep that motion because of inertia and it's something it holds on to, not that something that fades away which like I noticed in class when people were having trouble understanding the fact that stuff just doesn't slow down like you get something in motion in a frictionless world or no air resistance or not gravity or whatever, it's going to keep on going.	113
		FEV19	I would say that my preunderstanding was confusing to me, because I thought like before that, like an object moving for example like I would take the example, because we live in like, like I Would think that, the fact that we live in a world with so much friction, isn't like an idea to me that an object would just keep moving indefinitely because like it would stop because of friction but like at the same time that's a force that is being applied on the object and I just hadn't realized that.	114
		FFS49		115

		FFD49	Clairement	116
				117
				118
				119
				120
	Probe: How did you go from your pre-understanding to your present ideas about force and motion?	MEM18	For example, I don’t have an clear example in my mind right now, but I always focused on reaching my teacher every time after the lesson and tried to, like actually tried to prove him wrong with my ideas, not in an attempt of dismissing what he’s teaching me, but in an attempt to see what I have learned because he has a more accurate idea, a different perspective, when I listen to him speaking and teaching, he has a different perspective on how the world is going and I want that, so I try to tackle it, I try to challenge it, and when I technically lose these challenges, I’ll be changing my previously perceived idea, and every time my challenge is beaten, I’m one step forward into understanding how forces and motion, and all the course is trying to teach me.	121
		MET18	When we were doing the experiments as a group like they were like, the pre knowledge that we had when we were trying to solve the problems, and then we like came into like a general conclusion as a group, as to what we think is accurate, and then you consult with the teacher and he either approved what we were saying or he either disapproved it and then explained what was actually happening.	122
		FEU28	Obviously like my basic understanding of everything changed after I read, and I learned a lot of new things and my understanding did change a lot.	123
		FES28		124
		MFJ38		125
		FFL38	Pour l’inertie, quand j’ai fait l’ÉR j’étais vraiment perdu, je ne comprenais pas vraiment, puis après ça on a fait les Labotoriels et en faisant les Labotoriels j’ai compris un peu que comme, ok, il fallait que je le voie de mes propres yeux et en le faisant en même temps de me questionner, c’est comme je n’ai pas reçu la matière avant, puis je l’ai faite après, non comme j’ai appris en le faisant. Puis là, j’ai faite Ok comme, ma précompréhension elle a comme, je ne comprenais pas, mais là je comprends. Q : il me semble que j’ai compris ce que tu disais. Ce n’était pas comme deux phases tu as fait ça ensembles, comme quelque chose qui est interactif.	126

<table>
<tr><td></td><td></td><td>FFC48</td><td></td><td>127</td></tr>
<tr><td></td><td></td><td>FFK48</td><td></td><td>128</td></tr>
<tr><td></td><td></td><td>MES19</td><td></td><td>129</td></tr>
<tr><td></td><td></td><td>FEV19</td><td></td><td>130</td></tr>
<tr><td></td><td></td><td>FFS49</td><td></td><td>131</td></tr>
<tr><td></td><td></td><td>FFD49</td><td></td><td>132</td></tr>
<tr><td></td><td></td><td></td><td></td><td>133</td></tr>
<tr><td></td><td></td><td></td><td></td><td>134</td></tr>
<tr><td></td><td></td><td></td><td></td><td>135</td></tr>
<tr><td></td><td></td><td></td><td></td><td>136</td></tr>
<tr><td>8</td><td>Rate how each of the expressions (on the answer sheet) describes a force.</td><td>MEM18</td><td>
Note: the student said that a force does not act on a body. He was saying that it was a poor verbal description.</td><td>137</td></tr>
<tr><td></td><td></td><td>MET18</td><td></td><td>138</td></tr>
<tr><td></td><td></td><td>FEU28</td><td></td><td>139</td></tr>
<tr><td></td><td></td><td>FES28</td><td></td><td>140</td></tr>
<tr><td></td><td></td><td>MFJ38</td><td></td><td>141</td></tr>
<tr><td></td><td></td><td>FFL38</td><td></td><td>142</td></tr>
<tr><td></td><td></td><td>FFC48</td><td></td><td>143</td></tr>
</table>

		FFK48	Décrit mal une force ← → Décrit bien une force Diminue quand les corps bougent: 1 2 3 4 5 6 7 8 9 10 11 Décrit comment un corps agit sur un autre: 1 2 3 4 5 6 7 8 9 10 11 Cause le mouvement des corps: 1 2 3 4 5 6 7 8 9 10 11 Détermine comment la vitesse change: 1 2 3 4 5 6 7 8 9 10 11 Transférée à un corps suite au contact: 1 2 3 4 5 6 7 8 9 10 11	144
		MES19	Poorly describes a force ← → Properly describes a force Diminishes as the bodies move: 1 2 3 4 5 6 7 8 9 10 11 Describes how a body acts on another.: 1 2 3 4 5 6 7 8 9 10 11 Causes bodies to move.: 1 2 3 4 5 6 7 8 9 10 11 Determines how the speed changes: 1 2 3 4 5 6 7 8 9 10 11 Transferred to a body on contact: 1 2 3 4 5 6 7 8 9 10 11	145
		FEV19	Poorly describes a force ← → Properly describes a force Diminishes as the bodies move: 1 2 3 4 5 6 7 8 9 10 11 Describes how a body acts on another.: 1 2 3 4 5 6 7 8 9 10 11 Causes bodies to move.: 1 2 3 4 5 6 7 8 9 10 11 Determines how the speed changes: 1 2 3 4 5 6 7 8 9 10 11 Transferred to a body on contact: 1 2 3 4 5 6 7 8 9 10 11	146
		FFS49	Décrit mal une force ← → Décrit bien une force Diminue quand les corps bougent: 1 2 3 4 5 6 7 8 9 10 11 Décrit comment un corps agit sur un autre: 1 2 3 4 5 6 7 8 9 10 11 Cause le mouvement des corps: 1 2 3 4 5 6 7 8 9 10 11 Détermine comment la vitesse change: 1 2 3 4 5 6 7 8 9 10 11 Transférée à un corps suite au contact: 1 2 3 4 5 6 7 8 9 10 11	147
		FFD49	Décrit mal une force ← → Décrit bien une force Diminue quand les corps bougent: 1 2 3 4 5 6 7 8 9 10 11 Décrit comment un corps agit sur un autre: 1 2 3 4 5 6 7 8 9 10 11 Cause le mouvement des corps: 1 2 3 4 5 6 7 8 9 10 11 Détermine comment la vitesse change: 1 2 3 4 5 6 7 8 9 10 11 Transférée à un corps suite au contact: 1 2 3 4 5 6 7 8 9 10 11	148
				149
				150
				151
				152
9	Rate how the activities (on the answer sheet) helped you shape your ideas about force and motion.	MEM18	Not helpful ← → Very helpful Reflective Writing: 1 2 3 4 5 6 7 8 9 10 11 Class Discussions: 1 2 3 4 5 6 7 8 9 10 11 ercises/Problems: 1 2 3 4 5 6 7 8 9 10 11 sts/Exams: 1 2 3 4 5 6 7 8 9 10 11 Concept map: 1 2 3 4 5 6 7 8 9 10 11 Labatorials: 1 2 3 4 5 6 7 8 9 10 11	153
		MET18	Not helpful ← → Very helpful RW: 1 2 3 4 5 6 7 8 9 10 11 Class Discussions: 1 2 3 4 5 6 7 8 9 10 11 Exercises/Problems: 1 2 3 4 5 6 7 8 9 10 11 Tests/Exams: 1 2 3 4 5 6 7 8 9 10 11 Concept map: 1 2 3 4 5 6 7 8 9 10 11 Labatorials: 1 2 3 4 5 6 7 8 9 10 11	154
		FEU28	Not helpful ← → Very helpful Reflective Writing: 1 2 3 4 5 6 7 8 9 10 11 Class Discussions: 1 2 3 4 5 6 7 8 9 10 11 Exercises/Problems: 1 2 3 4 5 6 7 8 9 10 11 Tests/Exams: 1 2 3 4 5 6 7 8 9 10 11 Concept map: 1 2 3 4 5 6 7 8 9 10 11 Labatorials: 1 2 3 4 5 6 7 8 9 10 11	155
		FES28	Not helpful ← → Very helpful Reflective Writing: 1 2 3 4 5 6 7 8 9 10 11 Class Discussions: 1 2 3 4 5 6 7 8 9 10 11 Exercises/Problems: 1 2 3 4 5 6 7 8 9 10 11 Tests/Exams: 1 2 3 4 5 6 7 8 9 10 11 Concept map: 1 2 3 4 5 6 7 8 9 10 11 Labatorials: 1 2 3 4 5 6 7 8 9 10 11	156

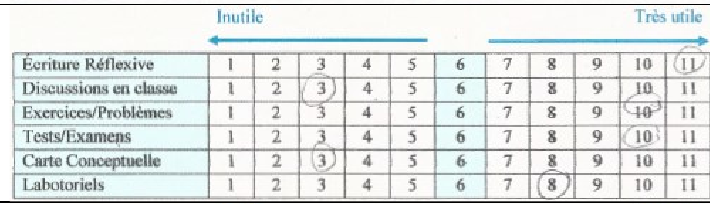
MFJ38



	1	2	3	4	5	6	7	8	9	10	11
	Inutile										Très utile
Écriture Réflexive	1	2	3	4	5	6	7	8	9	10	11
Discussions en classe	1	2	3	4	5	6	7	8	9	10	11
Exercices/Problèmes	1	2	3	4	5	6	7	8	9	10	11
Tests/Examens	1	2	3	4	5	6	7	8	9	10	11
Carte Conceptuelle	1	2	3	4	5	6	7	8	9	10	11
Labotoriels	1	2	3	4	5	6	7	8	9	10	11

157

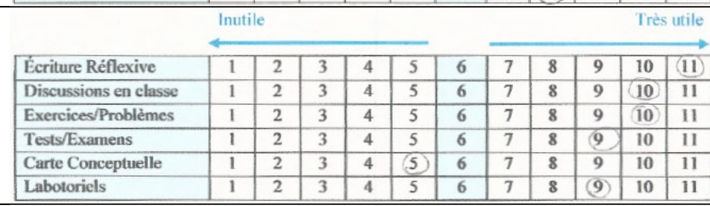
FFL38



	1	2	3	4	5	6	7	8	9	10	11
	Inutile										Très utile
Écriture Réflexive	1	2	3	4	5	6	7	8	9	10	11
Discussions en classe	1	2	3	4	5	6	7	8	9	10	11
Exercices/Problèmes	1	2	3	4	5	6	7	8	9	10	11
Tests/Examens	1	2	3	4	5	6	7	8	9	10	11
Carte Conceptuelle	1	2	3	4	5	6	7	8	9	10	11
Labotoriels	1	2	3	4	5	6	7	8	9	10	11

158

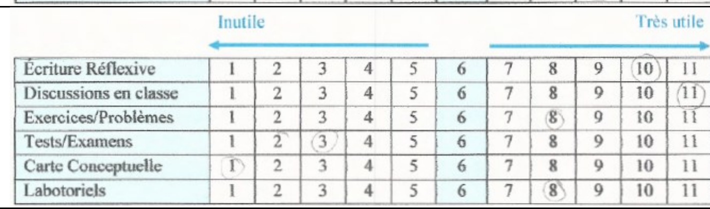
FFC48



	1	2	3	4	5	6	7	8	9	10	11
	Inutile										Très utile
Écriture Réflexive	1	2	3	4	5	6	7	8	9	10	11
Discussions en classe	1	2	3	4	5	6	7	8	9	10	11
Exercices/Problèmes	1	2	3	4	5	6	7	8	9	10	11
Tests/Examens	1	2	3	4	5	6	7	8	9	10	11
Carte Conceptuelle	1	2	3	4	5	6	7	8	9	10	11
Labotoriels	1	2	3	4	5	6	7	8	9	10	11

159

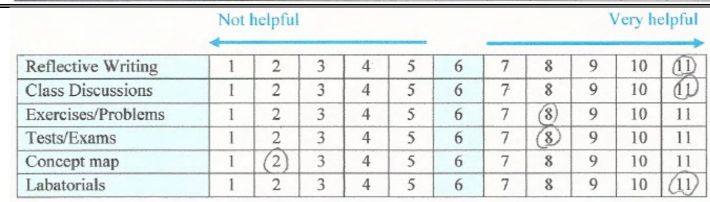
FFK48



	1	2	3	4	5	6	7	8	9	10	11
	Inutile										Très utile
Écriture Réflexive	1	2	3	4	5	6	7	8	9	10	11
Discussions en classe	1	2	3	4	5	6	7	8	9	10	11
Exercices/Problèmes	1	2	3	4	5	6	7	8	9	10	11
Tests/Examens	1	2	3	4	5	6	7	8	9	10	11
Carte Conceptuelle	1	2	3	4	5	6	7	8	9	10	11
Labotoriels	1	2	3	4	5	6	7	8	9	10	11

160

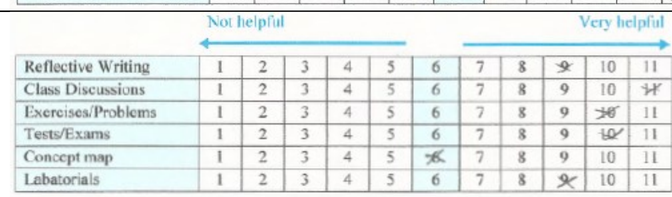
MES19



	1	2	3	4	5	6	7	8	9	10	11
	Not helpful										Very helpful
Reflective Writing	1	2	3	4	5	6	7	8	9	10	11
Class Discussions	1	2	3	4	5	6	7	8	9	10	11
Exercises/Problems	1	2	3	4	5	6	7	8	9	10	11
Tests/Exams	1	2	3	4	5	6	7	8	9	10	11
Concept map	1	2	3	4	5	6	7	8	9	10	11
Labatorials	1	2	3	4	5	6	7	8	9	10	11

161

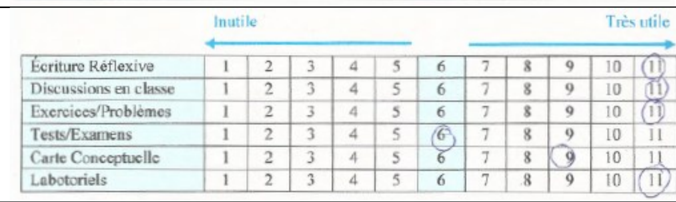
FEV19



	1	2	3	4	5	6	7	8	9	10	11
	Not helpful										Very helpful
Reflective Writing	1	2	3	4	5	6	7	8	9	10	11
Class Discussions	1	2	3	4	5	6	7	8	9	10	11
Exercises/Problems	1	2	3	4	5	6	7	8	9	10	11
Tests/Exams	1	2	3	4	5	6	7	8	9	10	11
Concept map	1	2	3	4	5	6	7	8	9	10	11
Labatorials	1	2	3	4	5	6	7	8	9	10	11

162

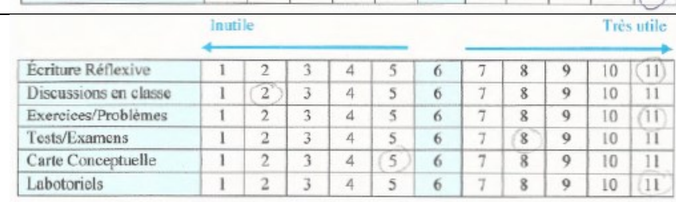
FFS49



	1	2	3	4	5	6	7	8	9	10	11
	Inutile										Très utile
Écriture Réflexive	1	2	3	4	5	6	7	8	9	10	11
Discussions en classe	1	2	3	4	5	6	7	8	9	10	11
Exercices/Problèmes	1	2	3	4	5	6	7	8	9	10	11
Tests/Examens	1	2	3	4	5	6	7	8	9	10	11
Carte Conceptuelle	1	2	3	4	5	6	7	8	9	10	11
Labotoriels	1	2	3	4	5	6	7	8	9	10	11

163

FFD49



	1	2	3	4	5	6	7	8	9	10	11
	Inutile										Très utile
Écriture Réflexive	1	2	3	4	5	6	7	8	9	10	11
Discussions en classe	1	2	3	4	5	6	7	8	9	10	11
Exercices/Problèmes	1	2	3	4	5	6	7	8	9	10	11
Tests/Examens	1	2	3	4	5	6	7	8	9	10	11
Carte Conceptuelle	1	2	3	4	5	6	7	8	9	10	11
Labotoriels	1	2	3	4	5	6	7	8	9	10	11

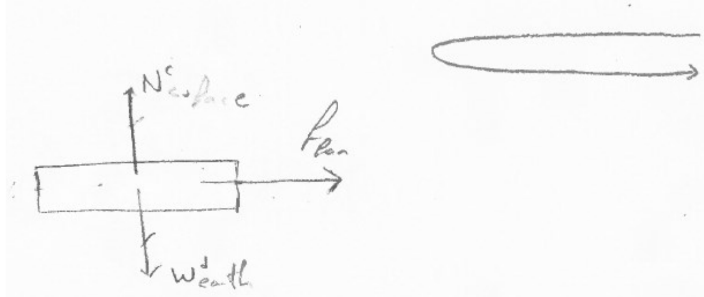
164

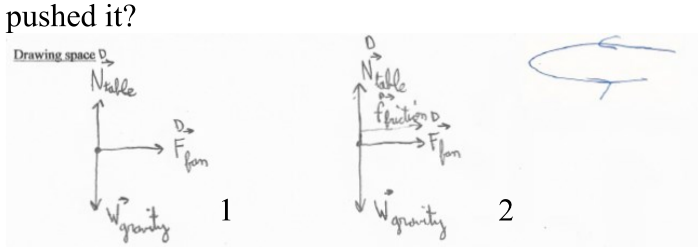
165

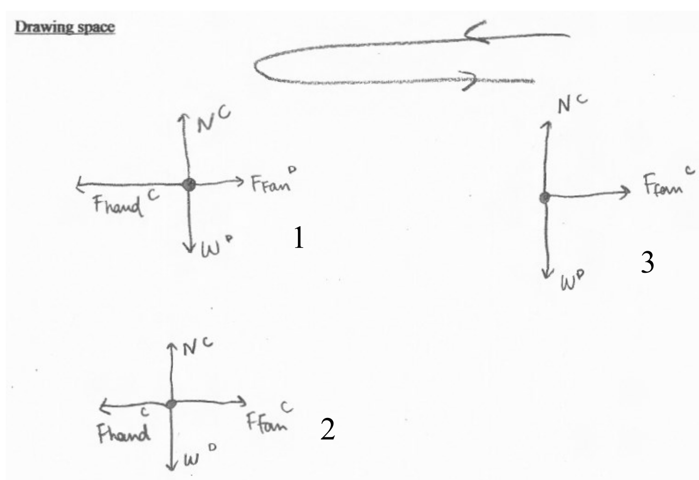
166

167

				168
	Experiment Analysis (Fan cart) The interviewer places the fan cart on the table and turns it on while keeping it from moving. The interviewer pushes the cart in the direction opposite to that dictated by the fan. The cart will move first in the direction it was pushed then it will move back toward the hand of the interviewer. The interviewer will ask: In this simple experiment there are forces and motion, can you please explain how they relate to one another?	MEM18	Just a comment this is one of the things that blew my mind, one of the things that help my pre-understanding crash down and rebuild again. I will try to describe it how I understand it now. Let's say the machine is working against your hand when your hand is holding it, there's a force applied by it on your hand and by your hand on it and, like there are other forces like the gravitational pull. Q: Just want to make one thing clear, is the fan exerting a force on my hand? No Q: Not the fan. Do you mean something else? The whole cart is exerting a force on your hand and your hand is exerting a force on the cart, I mean, and as you push it, because the force that you exert on it increases, and, so relative to the mass of the thing, You're exerting force on it, and it's exerting it back, however the effect on it is more obvious then the effect on you. If you keep pushing it enough you might find marks on your hand. Whatever force you're pushing on it, it pushes back on you, and because this force is stronger than the fan that is trying to push it in the other direction, you give it this force and it starts moving in the direction we don't expect it to move, and as it is moving because you gave it a push, you’re not like, you give it a push and you let go of it you're not constantly pushing it, this force is being like, if I can say it this way, is being countered by, what we expect from the fan to do, and it’s like, when it reaches a certain point, its equalized by the fan, and it reaches the velocity of zero, at the farthest distance from your hand. Q: what is equalized here again? When the velocity is zero, all the forces are equal. The force that you have applied on it, but not there anymore, has been, I don’t know if I can say it this way, equalized by the force of the fan pushing in the other direction, and as it reaches this point of zero velocity, then fan is still working, and goes back into pushing it in the direction you expect to move and goes back to your hand. Q: Can you draw a free body diagram of the cart when it is at the farthest point?	169

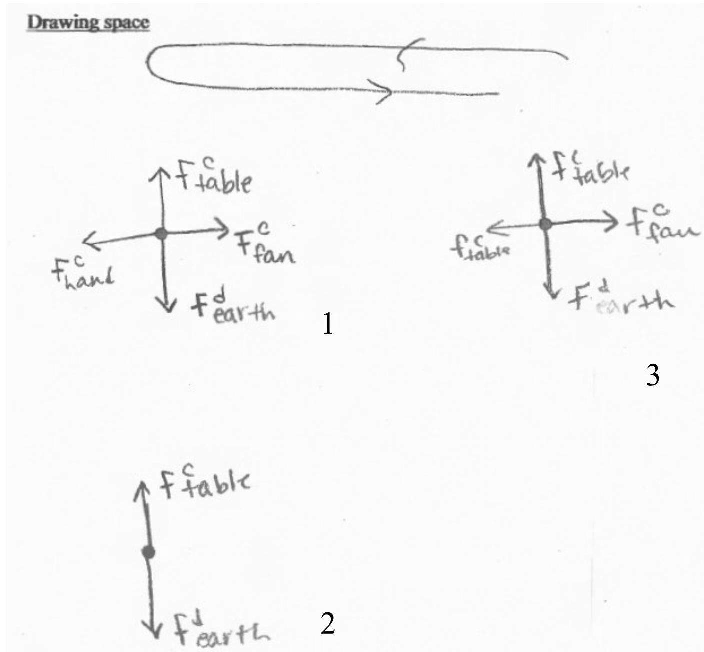
			 Note: at one point, while the student was drawing, he removed the force of the fan, then he put it back. The student stated that the normal and the weight are equal in magnitude. Initially the student drew a force of friction that balances the force of the fan. Q: What is this is the force? I don't know how to describe it but it's the fan pushing. Q: Very good, so this is the force exerted by the fan on the cart, this is what you're saying, so it's going to bring it back that way. What is this other force? This is the force of friction on the table, exerted by the table on the body and by the body on the table. Q: Okay, so this is the force of friction exerted by the table on the body and this is balancing the fan, the force of the fan? I don't know, yes and no. The force of the fan alongside the force of friction are balancing the force you exerted at the beginning to make the cart move in the other direction, balancing it as it moves, like, as it’s continuing to move, when the forces are at equilibrium, I mean I should have the friction in the other direction as well, then it will start moving backwards. Q: but at the peak, is there friction? No. Q: maybe on its way to the peak and on its way back there’s friction. Yeh, you are right. You know what I’ll get rid of this too (the students erased the force of the fan). Q: but the fan is still on. But at this point, there is no force exerted by it, it is equal to something that I don’t know how to describe. Q: I understand, let me ask you something, as if you are trying to make the forces balance at the peak, right? Yes	

			Q: my question to you, had they been balanced would it move back? No, it won't. And this is what I'm asking myself, I'm confusing myself. Q: Ok so why did it stop. It didn't stop. Q: But at that point you said that the velocity was zero. Yes, at that point it was zero but the whole motion didn't stop. Q: Very good I feel betrayed by my own self. Q: you did very well.	
		MET18	Initially when you pushed it, you were giving it a larger force then the fan can compensate for, so it was pushed in the left direction, but eventually after the force, after your hand had left contact with the cart, there was no more force acting on it, so it was only the fan pushing in the opposite direction, and friction, so it gradually came into a slow, and at the point where it just stopped, and then the fan was exerting a force on the air, I mean making the air spin, anyways, so it was exerting a force, and it made the cart go back in the right direction. Q: Okay very good, can you draw a free body diagram (diagram 1, below) of the cart when it was at the maximum point, the farthest point from where you pushed it?  Q: Okay very well, so what about on its way, I mean after the car left your hand, after you pushed the cart, on its way to its maximum point. Can you draw a free body diagram (diagram 2, above) of the card on its way, after it left your hand and before it reached the maximum point? Q: Okay when you put a D here, what does that mean? It's a direct force Q: By direct force you mean a contact force? Yes it's a contact force.	170
		FEU28	Basically there's a force acting this way, there are two forces that are acting against each other, and then the	171

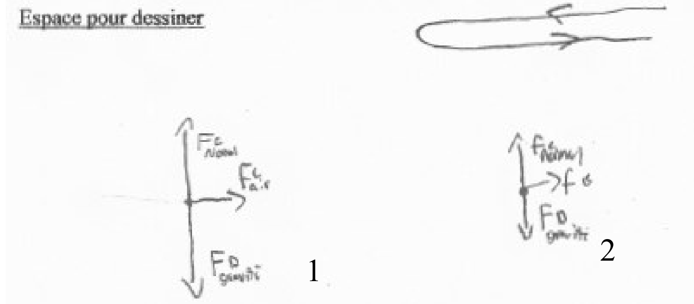
			moment, when I push, that's one of the forces and it’s greater than the force acted by the fan, so it obviously goes in the direction of the force that is applied in, but then once I let go of the force, the net force becomes only the force of the fan, yeah, so at some point, although my force is still reacted on the body, at some point it will kind of, not diminish, kind of, goes away I guess, and at some point it will stop, and then the only force is the fan. Q: Okay and why does it come back? Because the fan, of the force of the fan is going this way. Q: Okay very well, consider this phase, I push the cart, and the cart is no longer in contact with my hand, and this is the maximum point it reached, can you please draw a free body diagram (diagram 1, below) of the cart, when it's no longer in contact with my hand but before it reached its maximum point?  Q: So you said that the normal force, what is that? Is that a ‘’d ‘’? No no sorry this is a ‘’c’’ because the table is acting on the cart. Q: Very good, so this is the force of the hand and this is the force of the fan. You say here that the force of the fan is a force at a distance? Yeah, I'm sorry I just need to think a little bit Q: It’s not graded you know. Yeah, yeah, I think that it's…. Q: What's troubling you?	

			Cause I'm not sure, because the fan is obviously attached to the body, but the force of the fan is created when it's turning like this. Q: Do you know why when the fan is on the cart moves? Okay, yeah, because it's attached, so it's a contact. Q: you can keep it as it is but I think it's more contact than a distance. What about the force of the hand, you said that it's a contact force. Yeah but you've let go of it. Q: Yes my hand is no longer touching the cart, would there still be a force of the hand exerted on the cart? The force is still here but it just, it gets countered by this force, at the beginning before it reaches the endpoint, the force of the hand is still greater than the force of the fan. Q: Very well, but you're saying that it's a contact force. Would we put a force on a body if there's no contact? No Q: But you did put it? Yeah, I'm still thinking. No I think its distance because it's still acting on it, but not in contact with it. Q: But is it a contact force or a force at a distance? Like at the beginning, if we were to draw it in a few steps, right here, if it was at this step (the beginning) it would be a contact, but here it becomes a distance. Q: You mean a force at a distance? Yeah Q: So the hand exerts a force on the cart at a distance? (The student laughs) why is it funny? Because it's confusing me a little bit. Q: So do we put a contact force there? Yes, I'm going to keep it a contact. Q: Ok, let us say it reached its maximum point. Can you draw a free body diagram (diagram 2, above) at its maximum point? Q: You didn't draw any horizontal forces here. Yeah because it's, oh wait, no wait Q: So, at the end, there is no force exerted by the fan on the cart? There is, but it's the same as the hand so these become equal (at this point, the student adds two equal opposite horizontal forces to diagram 2). Q: So here they're equal (diagram 2) but not here (diagram 1) here, the force of the hand is greater and	

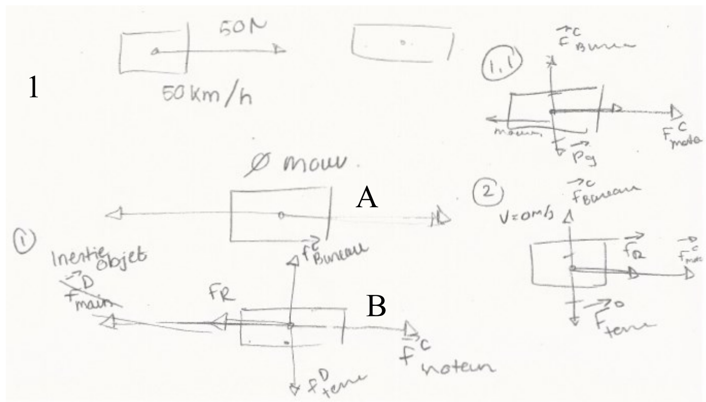
			that's why it moves forward. Ok, why does it come back? Because this becomes greater than the force of the hand. Usually there's something called inertia there's another external Force which means that it cannot stay in inertia and that's why it goes back this way, yeah. Because you applied the force usually there's an inertia but there's another force countering it, that means the force can't stay the same, the motion can't stay the same. Q: Ok, I understand, but when it comes to forces you drew, why does it come back? Because the fan's force is bigger than the hand's force. Q: Ok, can you please draw a free body diagram (diagram 3, above) on its way back? Q: And what about the force of the hand? I don't think it's there anymore. Q: So, at the end it becomes 0? Yeah. Q: And there is no more force going back. Alright.	
		FES28	So the propeller is on, when you give it an external push, to the opposite that it would move, to the force of the air, the fan, it will accelerate, and then there will be a change in its inertia, it will eventually get to a velocity like zero, and then it will start going in the opposite direction that it was initially going, because eventually, the force that you gave it wears off I guess, you could say so, as I said the velocity will get the zero, and then the force of the fan will cause it to move back, and this is also a part of air resistance. Q: When you said that the inertia decreases, what do you mean the inertia decreases? No there's a change in inertia. Q: You said the inertia changes. Yeah, so it's initially moving, and then, like, if an object is moving, it's going to stay like that, unless there's an external force applied on it, and in this case it would be I guess the propeller, because it's causing like, air resistance against the way that the cart is moving, so it'll eventually like come to a stop. Q: Can you draw a free body diagram of the cart from the moment it left my hand, so it's no longer in contact with my hand, after I pushed it, and before it reached its maximum point. Somewhere here, can you please draw a free body diagram (diagram 1, below) of the	172

			cart after it was pushed and before it reached its maximum point.  Q: You drew the force of the hand on the cart and what is the “C”? Contact Q: So, this is a contact force Your hand was on it Q: Yes, but we said that it was after the contact. I don’t know what the force is. I would assume, I don’t know. Q: You are saying it’s a contact force, but I don’t see any contact. Is there a force exerted by the hand on the cart in this case? No, but it’s moving. Q: It’s moving that way, you are right, it is moving that way. What if I ask you to draw a free body diagram (diagram 2, above) of the cart when it’s at the maximum point. I’m going to assume it stopped, I don’t think there is like a f…. but the fan is on, but it like it comes to a stop, so I don’t know. Q: You are saying that it comes to a stop, does it stop completely? Yeah, at some point, even though it’s for a bit of time, it doesn’t like full stop for like five seconds, but stops for like, I think yeah. Q: But as you said the fan is still on.	

			Yeah, so I don't know. Q: But is there a force exerted by the fan on the cart. Yeah. Q: But you didn't draw that. Because it's not moving. Q: Ok, let's say it's going back. Can you draw a free body diagram (diagram 3, above) on its way back. I think there is friction also here, but I don't know. Q: You can put it if you like. In this case, why would it slow down? Because the force of the fan is making it move in the opposite direction. Q: Yeah, but you drew the force of the hand too. Yeah Q: But if the force of the hand is pushing it that way, and the fan is pushing it the opposite way, why would it slow down? Oh, Oh, I know why, because the force of the propeller becomes larger than the force like you gave to the cart, like you initially did. Q: Alright, thank you.	
		MFJ38	Quand vous le pensez, vous appliquez le fort une force vers ma gauche plus forte que celle du vent qui pousse par-là, fait que, vous créez une force qui est plus grande, il va vers l'avant mais cette force, et continue tandis que vous vous avez juste donné une poussée donc la force va s'arrêter graduellement parce que la friction l'arrêt et l'autre force qui la contre elle va s'arrêter quand les deux forces annuler son égal donc la résultante nulle et après ça vu que votre poussé est terminée, l'énergie que vous avez donnée est arrêtée, ça va reprendre la force de l'air qui pousse oui ça va revenir. Q: Est-ce que tu peux dessiner un diagramme de force (Diagram 2, below) du corps du moment où je l'ai lâché jusqu'au moment où il atteint son point maximal sur le chemin du moment où ma main ne le touche plus jusqu'au moment où il atteint son point maximal? Est-ce que c'est important de dessiner la normale? Q: Oui on veut un diagramme de force. (Note: initially the student drew a force exerted by the hand on the cart)	173

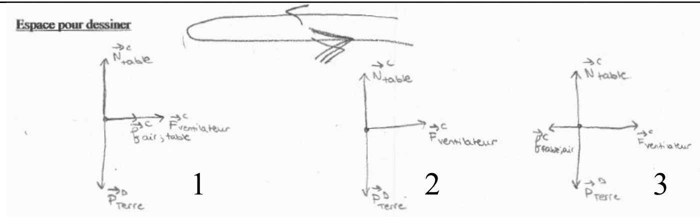
			 Q: Ça c'est quoi? C'est la force de votre main. Je ne me rappelle plus ce qu'il faut écrire. Q : Qu'est-ce que tu veux dire? Mais comme la lettre qu'il faut écrire. Q : On met un C pour contact ou on met un D pour distance. Mais j'ai écrit contact parce qu'il me semble… Q : Est-ce qu'une main peut exercer une force sur un objet sans contact? Non. Q : Mais j'ai demandé explicitement un dessin du chariot une fois que t'a main n'est plus en contact avec. C'est vrai ça. Q : Tu as mis que c'est une force de contact, mais il n'y a pas de contact. C'est vrai c'est l'inertie qui la fait continuer pour garder sa vitesse que vous avez donné. Q : C'est bien, donc ce n'est pas la force de la main? Non c'est l'inertie (Here, the student was about to draw the force of inertia). Q : Tu vas mettre la force de l'inertie? Oui. Q : Mais est-ce que l'inertie est une force? Non je ne pense pas. Q : L'inertie n'est pas une force. C'est vrai ce n'est pas une force. Q : Donc, est-ce qu'il y a une force comme ça? Non. Q : Mais pourtant il bouge comme ça. Humm, j'ai dû regarder mes notes de cours avant. Q : Tu fais très bien. Est-ce qu'il y a une force comme ça? Il y avait une force qui s'appliquait.	

			Q : Ok, il y avait une force, mais maintenant que tu l'as lâché, est-ce qu'il y a une force? Je pense p…, mais c'est sûr il y a la force du ventilateur. Q : Oui, Mais de l'autre côté, est-ce qu'il y a quelque chose? Non, c'est seulement l'inertie de votre poussée qui va garder la vitesse que vous avez donné. Fait que, il ne devait pas avoir de force. Q : Dit-moi pourquoi il s'arrête? Mais premièrement, parce que la friction arrête le chariot, puis deuxièmement parce que l'autre force veut arrêter l'inertie et la repartir de l'autre bord. Q : Dit-moi, S'il y avait une force comme ça, est-ce qu'il s'arrêtera? S'il y avait une force comme ça? Non il ne s'arrêterait pas. Q : Donc, est-ce qu'il y a une force comme ça? Non il n'y en a pas, parce que s'il y avait une force comme ça il ne s'arrêterait pas. Q : il y a tellement d'indices. Est-ce que tu veux une efface? (The student erased the force of the hand). Q : Tu a bien fait sans réviser les notes de cours. Est-ce que tu peux dessiner un diagramme de force (Diagram 2, above) quand il est à son point maximal, quand il est au bout? (the student draws only the weight and the normal) Il n'y a aucune des forces des deux bords qui est appliquée. Non, Humm, il y a quand même la force qui pousse de l'autre bord. Q : Est-ce qu'on a éteint le ventilateur? On ne l'a pas éteint, il applique quand même une force pour aller de l'autre bord. Q : Est-ce qu'il y a une force pour le ventilateur? Oui. Q : Elle est comment? Elle va par-là (He draws the force shown in diagram 2, above), sauf que, elle est entrain de, elle est nulle parce qu'elle est égale à l'inertie qui restait, elle l'a juste annulé pour aller de l'autre bord. Q : Si au bout elle était annulée, pourquoi il reviendra? Parce que le ventilateur est encore ouvert. Q : Mais tu es entrain de dire qu'il n'y a pas de force, tu dis qu'elle est annulée la force, comme elle est partie? Si elle était annulée, est-ce qu'il reviendra?	

			Non, c'est-à-dire qu'elle était tout le temps là. Q : Pourquoi il reviendrait si elle n'était pas là? Il ne reviendra pas. Q : Il doit y avoir quelque chose, non?	
		FFL38	Parce que c'est la force résultante. En le poussant ici, là la force résultante va aller vers là-bas. Est-ce que je peux dessiner? Q : Bien sûre. J'aillais même te le demander.  Là le moteur va faire en sorte qu'il aille vers là-bas. Là la force résultante va être vers là-bas. Mais là après ça, quand je vais le tenir ici, vu qu'il ne bouge plus, ça va être la même force, la même longueur, comme ça (at this point the student drew opposite horizontal forces shown in part A of the image above. The student also highlighted that there is no motion in this part). Il ne va pas avoir une résultante parce qu'il n'est pas en mouvement. Ensuite, quand je vais le pousser, m'a force résultante, la force de l'élan va être plus grande, donc la force résultante va aller vers là-bas. Q : Ok, tu peux la dessiner si tu veux. Ok je vais faire un autre dessin car celui-là il n'est pas en mouvement (the student starts drawing part B of the image above). Puis la comme plus ça va aller, moins la force que j'ai donné va grandir et là, la force résultante va diminuer et jusqu'à devenir nulle. Là il n'est plus en mouvement, et là, attendez, pourquoi elle va diminuer? Q : Quelle force? Elle que j'ai donné en élan. Oui je me souviens, quand on lançait une balle puis elle revenait, mais ça c'est la gravité, mais là ça va être le vent dessus. Dans ma tête c'est comme ça.	174

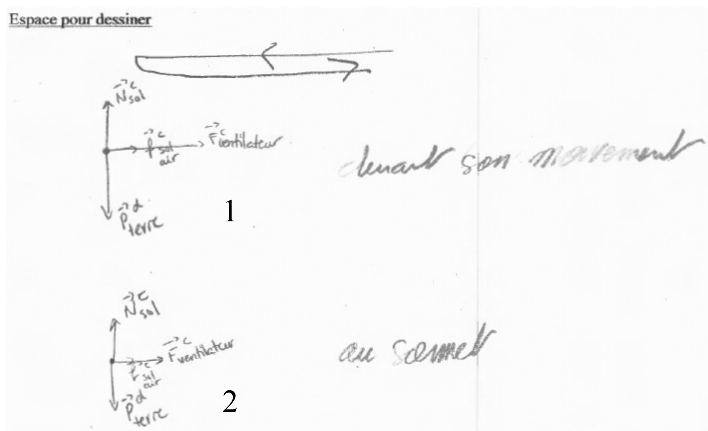
			Q : J'ai une question spécifique pour toi, disons que tu l'as poussé et ta main ne le touche plus. Il est en train de bouger. C'est l'inertie. Q : Est-ce que tu peux faire un diagramme de force là où il n'est plus en contact avec ta main, avant d'arriver au point maximal? Est-ce que tu peux aussi libeller les forces? Q : Est-ce que tu dis que la force de la main est une force à distance? Au début elle le touche, mais quasiment que je la touche plus, c'est l'inertie de l'objet qui veut garder son mouvement, donc je le touche plus. Q : Donc tu ne le touches plus, mais tu as dit ici qu'il y a une force à distance exercée par la main. Oui, mais on peut appeler ça inertie (the student changes the name of the force to inertia). Q : Mais est-ce que l'inertie est une force? On l'a vu en cours je pense. Q : Je ne sais pas, mais est-ce que l'inertie est une force? Moi je dirais non. Q : Tu dis que non, mais est-ce qu'on met une flèche pour l'inertie. Je sais que pour le mouvement on ne met pas une flèche au centre. Q : Donc tu as une flèche pour le mouvement, mais est ce que l'inertie est une force? Non, donc il n'y a pas une flèche. Mais pourquoi ma résultante sera de ce bord? Comment je pourrai la dessiner? Q : On dessine les forces ensuite on trouve la résultante. Tu as dessiné la force du moteur, ça c'est bien, que-ce qu'on va faire avec la force de la main? Elle est rendue une inertie, donc je l'enlève. Q : Ok, est ce que c'est toutes les forces qui existent sur le chariot? Non il y a ici la force de contact du sol, la normale, puis la même longueur la force à distance de la terre (the student was drawing while talking). Il y a le frottement aussi. Q : Donc elle est où la résultante? Donc elle est par là (the students was disapointed because it was opposite to the direction of motion). Q : Est-ce que tu as une preuve qu'elle est vraiment par-là? Comme le mouvement est d'un côté mais la	

			résultante est de l'autre côté? Est-ce que tu as une preuve qu'elle est vraiment par-là? Non pas vraiment. Q : Dis-moi, si la résultante était comme le mouvement, qu'est-ce qui arrivera dans ce cas-là? Mais ça va aller par là-bas tout le temps. Q : Oui. Oh my god, ça c'est vraiment intelligent, j'aime ça. Ok oui, c'est vraiment nice. Donc ma force résultante elle est par là, mais mon mouvement est, oui je m'en souviens, puis j'avais réussis ce numéro-là. Q : Je ne suis pas surpris que tu l'as réussis. Donc elle est où la résultante? Tu peux la dessiner maintenant si tu veux. Je veux un diagramme quand il est à son point maximale. (the student labeled the first diagram 1, then labeled the second 1.1, then labeled 2 the one about to be drawn) Il est en genre d'état d'équilibre, ça ne va pas dire que l'état d'équilibre ça ne bouge pas, je n'ai pas dit ça, mais il est comme en genre d'état d'équilibre, parce qu'il ne bouge pas, il n'y a plus de mouvement par là-bas, puis il y a encore la force résultante qui va aller par là-bas.	
		FFC48	La force de votre main quand elle pousse le chariot ça lui donne une certaine force en Newton qui va le faire, qui le fait avancer, mais plus il avance, de un son accélération va diminuer, la force donnée par votre main va diminuer, après par la suite il va, il revient, c'est la force du ventilateur qui pousse, qui pousse Q : L'air Oui l'air Q : Tu allais dire le vent? Oui (laughing) c'est ça ce que j'allais dire. L'air du côté et ça va le faire retourner en accélérant. Q : Ok, ok, je te demande maintenant de dessiner un diagramme de force (diagram 1, below) du chariot, du moment où ma main ne le touche plus jusqu'au moment où il atteint son point maximal. Choisi un moment entre ces deux-là et fait un diagramme de force du chariot. (The force of the hand was initially drawn on the body and the force of the fan was not drawn)	175

			 Q : Ça c'est quoi cette force? C'est la force de la main, ça provient de la main. Q : C'est la force que la main a exercé sur le corps? Oui Q : Tu as dit que c'est une force de contact? Oui mais maintenant c'est, dans le fond je ne suis pas sûre qu'il y a encore la force de la main. Q : je te répète, du moment où tu l'as lâché jusqu'au moment où il est à son point maximum, ça c'est la phase qu'on te demande. Oui Q : Est-ce que tu dis que la force de la main est toujours sur le corps même après l'avoir lâché? Non, c'est ça ce que j'ai écrit, mais je ne veux pas dire ça. Q : Mais tu peux changer si tu veux. Si tu veux. Parce que tu as mis que c'est une force de contact. Oui, ça serait plus une force à distance, mais je ne suis pas sûre qu'elle est encore présente. Mais est-ce que c'est une force par la main exercée à distance? Q : Est-ce que la main exerce des forces distance? Non Q : Tu sais ce qui arrive si les mains exerçaient des forces à distances? Oui ça ne serait pas bien. Q : Est-ce qu'il y a une force, un résidu de la force de la main? Non, il y a un résidu de la force de la main, mais elle n'est plus entrain de l'appliquer dessus. Q : Est-ce que ça s'appelle force? Non Q : Ok tu as dit non ça ne s'appelle pas force? Non, je ne pense pas. Q : Ok, j'ai appelé ça résidu, c'est comme il reste quelque chose ici, mais est ce qu'on l'appelle une force? Non, je ne pense pas. Q : peut-être effet? Oui Q : Mais est-ce qu'on l'appelle une force?	

			Non Q : Est-ce que le ventilateur pousse le corps? Il le pousse de ce côté. Q : Mais est-ce que tu as dessiné cette force? Non Q : Tu ne l'as pas dessiné, mais est-ce qu'il y a une force exercée par le ventilateur su le chariot? Oui Q : Donc il faut la mettre (The student adds here the force of the fan), tu l'as mis quand même dans le même sens que la force de frottement. Et la force de la main est-ce qu'elle reste, est-ce qu'on l'enlève? Non, je vais l'enlever (the student erases the force of the hand). Q : Pourquoi tu l'enlèves? Parce qu'au moment de cette phase elle n'est plus entrain de s'appliquer dessus, c'est l'inertie, mais Q : C'est l'inertie, tu peux l'appeler inertie Mais je ne peux pas la mettre dessus, mais. Q : C'est quoi l'inertie dans ce cas? Le corps a la tendance à continuer le mouvement qu'il était au début, quand la main a poussé le ventilateur il a commencé à aller de ce côté et même s'il n'y a plus la force de la main directement dessus il va continuer son mouvement jusqu'à ce que ça égalise avec le moteur. Q : Qu'est-ce qui égalise avec le moteur? Dans le fond, pendant qu'il va de ce côté, donc vers ma gauche, la force de la main est entrain de diminuer et la force du moteur est entrain d'augmenter. Q : Très bien, maintenant tu as dit la force de la main est entrain de diminuer. Oui Q : Mais est ce que cette force existe? Oui, mais Q : Tu viens de l'enlever, mais tu dis la force de la main va diminuer, donc elle est toujours là. L'effet de la force va diminuer Q : L'effet de la force va diminuer, ok, mais pas la force? Non Q : Ok, je te demande de dessiner un diagramme de force (diagram 2, above) du corps quand il est dans son point maximal, au point le plus loin. Q : Pourquoi tu as mis la force du ventilateur? Parce qu'elle est entrain d'exercer une force dessus.	

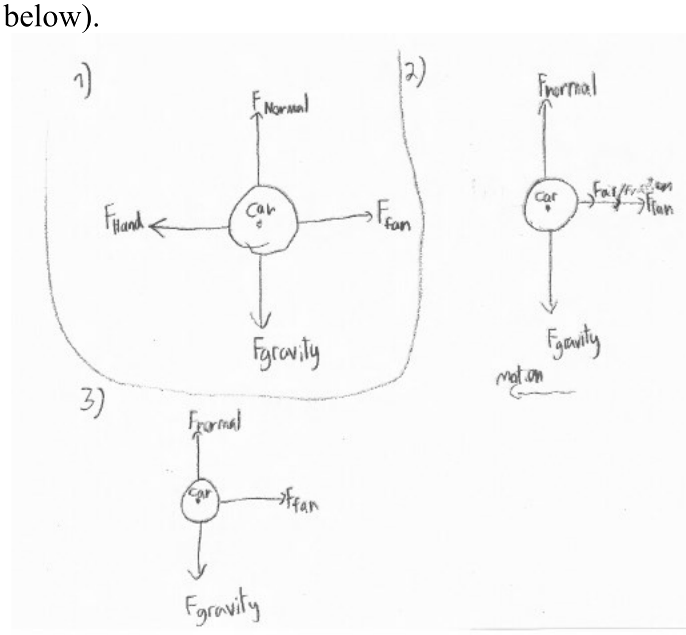
<table>
<tr><td></td><td></td><td></td><td>Q : Est-ce que tu peux dessiner un diagramme de force en revenant (diagram 3, above).
C’est ça.
Q : Merci.</td><td></td></tr>
<tr><td></td><td></td><td>FFK48</td><td>Quand tu le pousses, tu l’accélères, tu lui donnes une accélération, mais du moment où ta main arrête de pousser, ça commence à décélérer, uniformément en avant, puis ça va, puis à un moment la vitesse va être comme à zéro, mais l’accélération est quand même constante, parce que ça va aller dans l’autre sens, alors c’est comme positif, négatif, parce que c’est l’autre sens.
Q : je te demande maintenant de dessiner un diagramme de force (diagram 1, below) à un moment quand le chariot n’est plus en contact avec ta main mais avant d’arriver à son point maximal.



Q : Est-ce que tu peux dessiner un diagramme de force (Diagram 2, above) quand il est à son point maximal.
Comme vitesse zéro là.
Q : Oui si tu veux, quand il est le plus loin de ta main.
Q : Pourquoi il ralentit?
Un, à cause du frottement puis deux parce que la force du ventilateur lui pousse dans l’autre sens, comme il veut aller dans l’autre sens.</td><td>176</td></tr>
<tr><td></td><td></td><td>MES19</td><td>Note: when the interviewer was setting up the experiment, the interviewee said that this experiment looks like gravity and that the force of the fan is like the gravitational force.

So first of all, the fan when you turn it on a certain amount of motion due to the force of the fan applied by pushing the air out of the way and this is kinda like a constant force so I assume that this would reach like</td><td>177</td></tr>
</table>

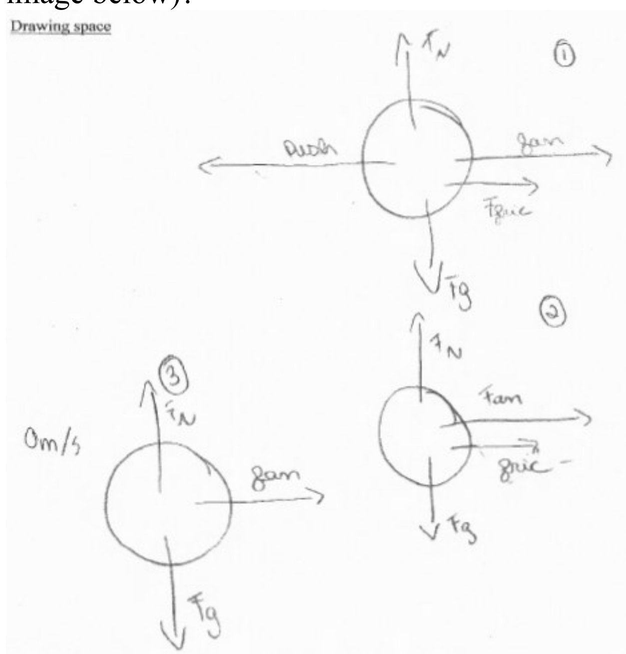
a maximum velocity at some point I don't know exactly when that would be whether it will reach it faster or not we have only done small experiments with this in class, but when you put your hand you're applying an equal force to that that is being applied by the fan and its stopping the cart from moving.
Q: ok this covers when the cart was held in place, what about when the cart was pushed to the other side?
So, your hand gave it a certain amount of force which transferred into motion that it was given, and eventually because we have this fan spinning and friction on the wheels that force would eventually come to stop, not the force, the motion would eventually come to stop, but even if there was no fan, it was just wheels, because of friction, but in this case it was friction and the force of the fan were pushing it in the opposite direction so it slowed down and it actually turned around and came back kind like when you take a pencil and you throw it up and down gravity is pushing down on it then it goes to a maximum height and comes back down.
Q: can you draw please a free body diagram of the cart when it was held by your hand, like when it was kept from moving by your hand (diagram 1, in the image below).



Q: can you draw a diagram of the cart after it left your hand (diagram 2, in the image above)
Q: can you draw one for the cart when it is at its maximum point (diagram 3 in the image above).

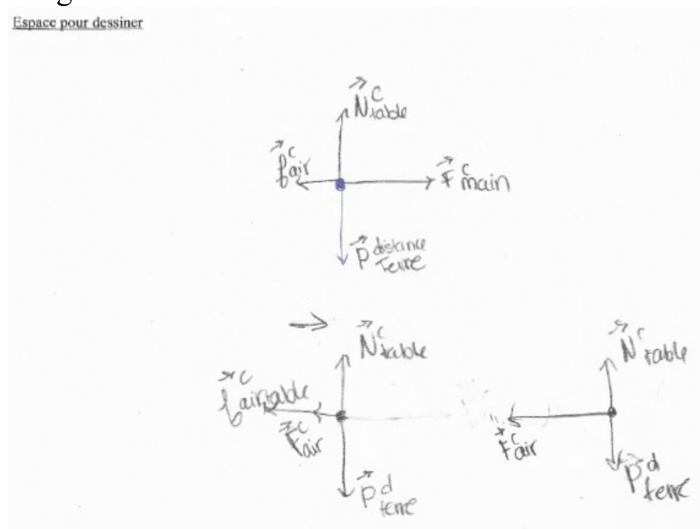
			Should I include air resistance? Q: yes, if you like Note: the interviewee drew that air resistance in the direction of motion. Q: Didn't you say that the cart was moving that way (in the direction of friction as it was drawn by the interviewee) Oh, yeah you are right. Note: the interviewee changed the orientation of friction Q: when the cart was at its maximum point, what was its velocity? Zero Q: Is it reasonable to have a force on the body when the velocity is zero? Yeah because there is the down force of gravity and the up force of the table. Q: What about the fan? Yeah, that's fair. There is also the fan. But for example, for your phone, the there's just the gravity and the table. Q: yeah, my phone is at rest, and here (fan at maximum point) the velocity is zero, is it the same thing? It depends. Is the fan on? Q: yeah, the fan is on, I mean the fan reached the maximum point and it came back. You said that at the maximum point the velocity is zero. Is it at rest? At that moment it's at rest because it is not moving, and when something has no motion it's at rest. But the minute it passes, it like almost breaks the seal, the fan finally overcomes, think of it in terms like of a hill, if you are pushing a rock up a hill, when the rock reaches the top of the hill and no longer have to give it a force and the fan starts to push it back. Q: as you said that there is a force pushing it that way (in the direction of the motion). Is there a force pushing it that way? Well there is no force there, unless you are pushing it all the way. I was thinking in terms of you pushing it just at the beginning.	
		FEV19	Can I like, draw a diagram? Q: Of course, you can draw whatever you like. When you push it, it goes in that direction until the fan starts to move it that way (opposite direction), You	178

push it and you apply a force on it, and then the force will keep going, like inertia, but like, then another force is applied which is the fan and that brings it in the other direction and then there is friction which we have to take into account and the air resistance.
Q: ok, but when you said now, we have a fan which applies a force, I mean wasn't that force applied when you pushed it?
Yeah but the force from when you pushed it, like, you applied a force when you pushed it but it's getting overridden by the fan.
Q: Can you please draw a free body diagram when that cart was pushed with the hand (diagram 1 in the image below)?

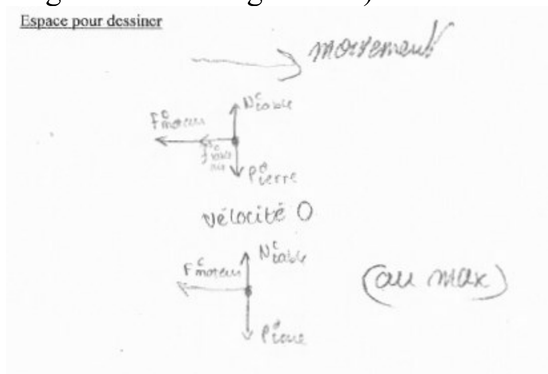


Q: can you draw a free body diagram of the cart when it is no longer in contact with your hand (diagram 2 in the image above) somewhere between the maximum point and after the cart left your hand?
Q: you did not put the force exerted by the hand on the cart?
Yes, because it is no longer in contact with the cart.
Q: let's say now that the cart has reached its maximum point, can you please draw a free body diagram when it is at the maximum point?
Would it be still at this point?
Q: (while showing the motion of the cart) at some point the cart reaches its maximum distance, can you draw a free body diagram when it reaches its maximum?

			Wouldn't it just look like this (the interviewee points at the second diagram), except for the friction, maybe when its starts going in the other way then the friction would be in the other direction. Q: So, you are saying it's like the second diagram only without the friction? Yeah, the friction would be there somewhere it depends on which way it was going. Q: ok, can you please draw it (the interviewee draws diagram 3 of the image above). Yeah, but is it still? The fan is still working right. Q: (while operating the fan cart) Well Is the fan still working? Yeah. Ok, but I'm not sure about the friction because I don't know which way it's going. Q: So, what is the velocity of the cart at this point, when it's at the maximum? I would say its zero because it's turning back in the other direction. Q: Can you please add it to the diagram. (the Interviewee adds it to the diagram) Q: Is it possible to have a body with a zero velocity when there is a force acting on it? Hmm… Because I don't know, here (at the maximum) does it stop or does it…like…cause when you are throwing an object in the air for example, like at the point where it reaches its highest point is when it get to zero m/s, so would it be the same with this? But there is still a force acting on it, it would have its highest velocity at that point? But then it wouldn't, because its then when it stops and goes back in the other direction.	
		FFS49	La force de ma main est supérieur à la force des molécules de l'air qui les pousse là-bas (in the opposite direction), donc la ça va venir ici mais à un moment donné, vu que ma main ne reste pas en contact avec l'objet, donc dès que, la force des molécules d'air va devenir supérieur à la force qu'il y avait de ma main, donc ça va compensée la force de ma main et l'objet va rebrousser chemin. Je ne sais pas si ça fait du sens. Q; Ok, est ce que tu peux dessiner un diagramme de force au moment où ta main était en train de le pousser? La main est en contact?	179

			Q : Oui, c’est durant la poussé. Note: The interviewee draws the first diagram in the image below  Q : j’ai une question, ça c’est quoi cette force (pointing at the force by the air)? C’est une force de frottement de l’air Q : c’est la force de frottement de l’air ou bien c’est la force du ventilateur? C’est la force du ventilateur, Q : mais tu l’as appelé une force de frottement! Avec les molécules d’air Q : Est-ce que tu veux dire que c’est la force des molécules d’air qui le pousse à avancer? Oui Q : Donc tu veux dire que c’est une force motrice et non une force de frottement Oui Q : Est-ce que tu peux dessiner un diagramme de force au moment où tu as lâché l’objet, c’est entre l’avoir lâché et avant d’arriver à son point maximum (the interviwee draws the lower middle diagram on the image above, only without air friction)? Q : Quand tu le bouges il n’y a pas de frottement avec la table, l’air? Q : Est-ce que tu peux mettre le sens du mouvement? (The student adds an arrow over the diagram along the friction forces). Q: Mais ça c’est la force de ta main. Oui oui, c’est de l’autre côté (the student draws the arrow over the diagram as shown in the image above after a few hesitations, then the student reanalyzes the	

			situation and draws the arrow, but now the student inverts the arrow of the fan). Q: Tu as changé la force du ventilateur, mais est ce que le ventilateur a changé? (now the researcher runs the experiment again, the student runs through all the step one more time and draws the diagram in the image) Q: Est-ce que tu peux faire un dessin de force quand l'objet atteint son point maximum? (the student draws the 3rd diagram in the image above). Q: Est-ce que c'est logique pour toi? Qu'il rebrousse chemin? Q: Oui Oui Q: Pourquoi? La force motrice du ventilateur va finir par compenser, c'est ça, va être plus forte que la force de frottement. Q : Ok, et qu'est ce qui va arriver par la suite? La résultante va finir par, comme côté vectoriel, la résultante va finir par, elle va être de l'autre côté, donc ça va rebrousser chemin.	
		FFD49	Donc on sait qu'il y a une force exercée par le chariot qui va dans ce sens-là (the direction of the push of the fan). À cause du frottement d'air que ça crée il y a du frottement d'air qui va s'opposer à ce mouvement la et votre main aussi. Donc là, le fait que vous contrez cette force-là, ça fait que les deux forces, puisqu'elles sont égales, ça va créer qu'il n'y a pas de mouvement. Donc le fait que vous le repousser, ça veut dire que la force que vous avez exercé avec votre main va être plus grande que la force exercée par le chariot lui-même, et après ce moment-là, il va quand même avoir la force du chariot qui va être exercée pendant tout le temps de l'expérience et donc ça va faire que quand vous avez cessé de toucher et de donner votre élan au chariot la résultante va quand même dans le sens opposé de ce que vous poussez avec votre main. Et donc, le fait que cette résultante-là, est présente et à cause de l'inertie qu'avait le chariot, ça va faire que le mouvement que vous avez créé, ça va finir par s'arrêter puisque la résultante est opposée à ce mouvement-là, et donc ça va causer que le chariot va revenir à sa position initiale. Q : très bien, tu étais méticuleuse dans ta description. Je vais te demander de faire un diagramme de force du chariot après l'avoir poussé avec ta main mais avant	180

			son point maximum (the student draws the first diagram in the image below).  Q : Est-ce que tu peux dessiner un diagramme de force à son point maximum, au point de rebroussement chemin? (the student draws the second diagram in the image above) Q: Donc tu as gardé la force du ventilateur mais tu as enlevé le frottement Oui parce qu'il est au moment où est-il est au repos, mais pas au repos mais quand ça vitesse est nulle.	
				181
				182
				183
				184
10	Did Labatorials help you in examining your ideas or were they a waste of time? How?	MEM18	I think I answered that before, it was one of the most enjoyable important parts for me in the whole course, even though I'm not inclined toward the experimental side or aspect of physics, because it destroys some of the ideas I have, but in terms of importance for learning it has huge significance.	185
		MET18	They were helpful.	186
		FEU28	I don't think they were a complete waste of time, but there were moments where I felt like I don't understand like, what it's supposed to lead me towards, like it's harder, because of the way I guess, our school is constructed, You are evaluated based on whether or not you can complete or pass your exam, and I personally am not able to put down what I'm able to experience in real life down on paper and use what I experienced in real life into an exam and a test. So the Labatorials didn't particularly help me, what usually helps me is exercises because they actually leave me to like, to know what to do during an exam like, we're not tested on whether or not like, during the test we're not tested on whether or not we can draw a free body diagram like, a real motion, like a real body that's	187

			moving around so, that like helps me in some ways but it won't help me for example complete my physics course because I can't apply it in a test and that's what allows me to pass my test.	
		FES28	I think they were good, they were sort of long though, so like it took us more than one class to go through it, and I find like at that point my brain was like, sort of, like I'm being honest, it was really fun. Q: But it was too long. Yeah I got tired of it, at like the end of it, because there was like so many pages, and there is still, there was like still questions I didn't complete, in some of them, and also they were helpful too, but I don't know, I got off track sometimes, but like that happens in every class, but in my understanding, the Hands-On part helped.	188
		MFJ38	Les Labotoriels m'ont beaucoup aidé, parce que on fait, mettons on voyait une loi qui faisait quelque chose, après ça on va utiliser le matériel pour produire une situation, et pour vraiment nous donner une meilleure idée de c'est quoi, et comment ça fonctionne, donc c'était très utile.	189
		FFL38	Ils m'ont aidé, mais aussi comme je vous ai dit, il me font sentir vraiment stupide des fois, parce que comme mon cerveau il fonctionnait comme, tu sais le temps que je me cherchais ça, je me sens stupide, mais comme vers la fin, je me disais finalement je l'ai trouvé, je ne sais pas, c'était vraiment une remise en question de moi-même. Je rochais un peu pour pouvoir le finir, une fois j'étais comme, ok là, ce n'était pas mon matin, ce ne me tente pas faire une Labotoriel, je me suis mis de même, le prof est venu me voir, il m'a dit voyons, c'était la première fois qu'il ne me voyait pas faire un labo. Mais parce qu'avant c'était toujours facile, j'avais la classe on apprenait les choses, puis je faisais le laboratoire, mais je me remettais pas en question, j'appliquais les règles, puis j'aimais ça moi, c'était la routine. Tandis que les Labotoriels m'ont remis en question et à la fin j'aimais ça.	190
		FFC48	Ce n'était pas une perte de temps du tout, selon moi, je ne sais pas si je peux parler pour les autres filles, mais en tant que groupe, ça nous a aidé beaucoup. On a trouvé que ça a mis nos idées en place, plus c'est une bonne façon d'apprendre la matière. Parce que on analyse nous-même et on crée des liens par nous-même.	191

		FFK48	Pour moi, avec les équipes de cinq, c’était beaucoup, alors il y avait d’habitude trois personnes qui faisaient le travail, puis deux qui ne faisaient pas vraiment grand-chose qui écoutaient, mais c’était comme un peu ennuyant. Q : Tu étais dans quelle partie? Moi je ne faisais pas grand-chose, honnêtement, mais ce n’est pas parce que je ne comprenais pas, je comprenais déjà, puis j’écoutais, comme ma façon de travailler est vraiment différente des filles de mon équipe aussi, comme elles étaient comme on décortique les idées, et elles pensent, what if it’s this, et whatever et moi j’étais comme, c’est plus simple que ça, je ne pousse pas aussi loin mes idées, mais je comprends quand même. Je ne sais pas. Q : Dis ce que tu veux, ça c’est le but. Moi mon exemple c’est que comme sur un examen, j’ai eu comme tous les points sur une question et j’avais répondu comme avec deux ou trois phrases, mais qui comme expliquaient bien, comme simple, mais comme d’autres personnes ont comme écrit des paragraphes qui disaient comme en fait la même chose. Alors les filles que je travaillais avec étaient comme ça. Alors elles avaient la réponse déjà, mais comme elles devaient voir toutes les possibilités avant, alors ça prenait beaucoup de temps, et j’étais comme, je n’aime pas ça. Q : Donc tu dis que c’était une perte de temps? Je dirais que c’est bon de faire des exercices pour voir, comme les expériences, nous permet de voir comme l’application de ce qu’on voit en classe, et ça je pense que c’était bon, je pense juste qu’il y avait trop de personnes dans les équipes.	192
		MES19	I think they were, especially the free body diagrams stuff, because like I’m a pretty forgetful person, I get distracted, so a part of that is like for example like forgetting the friction earlier, I forgot that, and I had to go back. So, it kinda helps at the time, remembering exactly what I have to put down especially for a test, when you have to do a free body diagram.	193
		FEV19	I think they did help like sort of understand what we were reading before Labatorials. Q: you mean when you read and you did the RW. Yeah. Q: So you are saying that they were not a waste of time.	194

			No	
		FFS49	Non ça ma aider à examiner mes idées. Q : Comment? Est-ce que tu peux nous donner un exemple? Donc premièrement, avant que le prof vienne voir chacune des équipes, il y a une première discussion entre nous, pas tout le monde a les mêmes idées, mais parfois deux ont une partie de l'idée et on finit par mettre ça en commun, parfois on va tous se tromper et en plus quand le prof vient dans chaque petit groupe ça vient en fait soit confirmer ce que nous avons mis ensemble ou complètement le détruire, car c'est complètement l'inverse. Comme un exemple spécifique…. Je ne sais pas	195
		FFD49	J'ai l'impression que c'était vraiment beaucoup plus utile que les discussions en classe ca permettait d'avoir une mini classe avec juste quelques élèves puis c'était facile de se comprendre entre nous et l'idée que le prof vient et nous aide à mieux comprendre les concepts, pour moi ca a vraiment été très utile pour vraiment, mettons la loi de Newton pour toute relier les éléments qui l'englobent à cette loi la et c'est ça que j'ai vraiment trouvée plus intéressant que mettons quand on est en classe et c'est facile de se distraire et c'est facile de décrocher et que là, vue que les questions des autres viennent moins nous toucher et on n'a pas parlé avec eux avant ça fait que c'est encore moins pertinent et agréable pour la personne qui écoute.	196
				197
				198
				199
				200
	Did Labatorials help you reach your expectations of the course?	MEM18	Well my expectations of the course, as I specified in the beginning, was complete enjoyment, and it gave me like this satisfaction and disappointment of what ideas I had but, it's also gave me satisfaction of how beautiful things work, so I guess the answer is yes.	201
		MET18	Yeah, I think they brought out, so we were put into groups, and then we had group discussions, along, in relation with the experiments that were going on, that way like, ideas were like, put forward and we could like discuss it, which was the most logical seeming one, and I think like group discussions really worked for me, I like that style of learning. And after like, we came to the best possible conclusion for this	202

			experiment, and then we went to the teacher, and then like we had like free time with him, so if we didn't understand something he could really explain it to us, in depth, whereas in a lecture form you wouldn't be given this much attention.	
		FEU28	Not really because not only we've done the Labatorials, we spent like around three, four months on Labatorials, it's like the end of the year and, I realize that I still have a lot of trouble, like doing forces and, we were doing Force exercises in class, we had little assignments on forces and I realize that I still don't understand, I understand a little bit how to do the questions because in some Labatorials we would have to do some calculations, but a lot of the questions they were boarded differently, they were searching for another variable and I wouldn't be able to solve the question because I just don't know enough material.	203
		FES28	Yeah because I find physics is something that you have to do, like hands on. I think you can't just learn it with a marker and like a whiteboard. You actually have to do the things to see like what is happening, and from that you can like interpret and do like the calculations.	204
		MFJ38	Oui, tout autant des notes de cours ou n'importe quoi. Ça m'a autant aidé à apprendre la matière et apprendre la physique en général.	205
		FFL38	Oui, ça m'a vraiment donné le gout, j'ai toujours aimé la physique, mais en faisant les Labotoriels, ça m'a fait poser des questions, puis comme là ça m'a donné le gout de faire des études en physique plus tard. Q : Oh cool. Moi j'étais comme oh my god j'aime ça poser des questions, je trouve ça vraiment cool.	206
		FFC48	Oui parce que je voulais vraiment, je suis une personne quand même visuelle, j'aime ça quand je le vois devant moi, et quand ce n'est pas seulement expliqué sous forme de théorie au tableau. Donc le fait que on l'a mis en place, mais comme le Labotoriel est comme un mini exemple de la théorie qu'on est en train d'expliquer, fait avec des matériaux qu'on peut vraiment voir l'effet, ça a beaucoup aidé.	207
		FFK48	Je ne pense pas, non.	208
		MES19	I think so	209
		FEV19	What do you mean? Q: when you take a physics course you expect to learn physics, did they help you learn physics?	210

			I think they did yeah, and also like the teacher would refer back to the Labatorials and make you realize that, like ok I see it, like you would see it in practice.	
		FFS49		211
		FFD49		212
				213
				214
				215
				216
11	What would you change in Labatorials?	MEM18	I guess questions, in the laboratory we have to make comments about, as we do the experiments, but had there been more questions for one to ask themselves like for example like the ones you're asking me at the moment while I was trying to figure out the answer, draw a free body diagram of this… had there been similar questions, or questions to force you to think… I mean ask you to think and question the way you were thinking about things and how they are happening, I think it would have been much better, to give bases to whatever we are experimenting.	217
		MET18	I don't know, they were like quite well designed, I can't think of anything specific.	218
		FEU28	I think that maybe, I mean I understand like your point of view or your goal of this, for us to be able to apply this in real life and learn ourselves through real life motions, and I think it's a really good goal. But like as students, it's just harder for us to apply this in school I guess, If that makes sense. So I think that maybe per Labatorials, like maybe not have everything based on like a real motion but have like doing a real motion thing, and a real motion exercise and analyzing that exercise. And then in the next exercise we would aboard a problem and have to use what we learned or discovered from the previous real motion exercise, and apply that into the non-real motion, like the text exercise.	219
		FES28	Q: what would you change in Labatorials other than make them shorter? I don't know.	220
		MFJ38	Dans les documents, quand ça disait Arrête. Il y avait des endroits où il fallait arrêter pour demander au professeur, je pense que c'est mieux d'arrêter juste à la fin, pour poser des questions mais pas pour plein de fois en plein milieu, parce que des fois on est vraiment dedans, ça brise un peu le rythme.	221

			Q : tu sais que le but de faire des arrêts c'est de juste s'assurer que les élèves, imagine qu'une équipe a fait une faute dans la première activité, elle va faire la même faute dans la deuxième, dans la troisième, dans la quatrième. C'est juste pour ne pas voire des élèves qui trainent des fautes sur un travail de deux heures de temps. Mais en même temps, peut-être ça serait bien, je ne sais pas, quelqu'un me l'a déjà proposé, il me dit : est-ce qu'on peut par exemple continuer à travailler et quand même réserver une place, comme ça pour ne pas attendre le prof avec les mains croisées comme ça. Est-ce que tu trouves que c'est une bonne idée de laisser les élèves continuer et laisser la chance au prof de vérifier ce qu'ils ont fait. C'est-à-dire pour ne pas être bloqué. Je pense qu'il n'y a pas nécessairement besoin d'arrêt, juste que le prof il passe équipe par équipe pour regarder que ce qu'ils font, mais nécessairement arrêter. S'il voit qu'il y a une erreur, qu'il le mentionne, mais devoir arrêter et attendre, parce que surement le prof. Q : C'est ça, éliminer l'attente, juste continuer le travail tout en gardant, tout en disant au prof, qu'on a terminé la première activité est ce que vous pouvez venir la vérifier.	
		FFL38	Il fallait que je demande au prof pour pouvoir continuer, mais c'était long, parce que là il doit passer par les autres.	222
		FFC48	Je ne sais pas quoi dire, d'après moi il n'y a rien à changer. Q : Par exemple, la durée d'un Labotoriel est ce que tu trouves qu'elle est correcte? Je trouve que la durée était correcte. Q : Et les pauses d'analyse, on vient discuter. Ça a aidé vraiment beaucoup parce que, dans le fond, le faire en équipe, ce n'est pas nécessairement, ça se peut qu'il y ait de bons aspects mais on a aussi des fautes donc, quand on le discutait, ça nous aidait à se rendre compte de nos fautes et non pas continuer avec la même idée du début pour tout le Labotoriel. Donc ça a aidé de mettre les idées au claire ensuit continuer.	223
		FFK48	Le nombre de personnes par équipe. Q : Quel est le nombre idéal que tu trouves? Trois, deux ou trois, je pense.	224
		MES19	I think it would probably be worse, since like this is where a lot of people developed, like their big	225

			understanding of seeing things in real life. Like it's one thing to hear about something and it's another thing to actually see it. So one thing that helped was like having a class discussion then doing a Labatorial about the class discussion so you see on one hand what we talked about and he'll do like an example with the pencil, throw the pencil up, and then he'll say , well now we are basically doing the same thing but instead of gravity being the acting force pushing it down, it's the fan, and there is friction from the table, so it's kinda cool to see the flip from the y axis to the x axis in terms of that Q: what would you change in Labatorials? I mean if you had the chance to change something. How would you do them differently? If you can think of anything. No Q: what about the discussions in Labatorials, there were like points where you had to discuss stuff with your teacher, or with your fellow students. Was that good, was that bad, was that a waste of time? I thought it was good especially the fact we did it in groups and I liked that we were supposed to consult the teacher while doing the lab cause for, I guess in this case especially since it was as we were learning these, but for other classes I mean, your obviously not supposed to talk to the teacher in the lab and they can't answer certain questions, but I liked that for this, you went to see them before you went on to the next step. The next step probably involved something you needed from the previous step, so for me if I'm making a careless mistake, like I kinda forget to do something, like friction, I'd go see him and he reminds me and I have that for the next time I do a free body diagram.	
		FEV19	No Q: what about the discussions, I mean did you like the discussion that went on in the group. Like when the teacher would come and discuss stuff with you? Was that good, was that bad, was that confusing? No, I think that helped me understand what we discussed about the Labatorials. Like the teacher would explain what was going on. Q: Did that help you understand? Did that help you eliminate confusion? I'm the kind of person who likes, like I don't like learning, just like on my own, like independently, like	226

			reading stuff and figuring out by myself, like I like to ask people questions, and this is like I thought that the discussions were helpful.	
		FFS49	Vous savez dans chaque groupe il y a des leaders c'est normal ils vont plus mener le projet c'est toujours comme ça on ne peut pas l'empêcher mais peut-être faire une petite sensibilisation avant les Labotoriels comme quoi il faut vraiment laisser chaque personne s'exprimer parce que parfois il y a des personnes qui vont dominer mais pas d'une bonne façon pas un bon leadership il vont baisser les autres en disant c'est moi qui a raison, mes idées sont correctes. Peut-être sensibilise sur l'écoute des autres et vraiment c'est un travail d'équipe et non une personne qui est sensée faire le tout.	227
		FFD49	Peut-être avoir plus de temps, il y avait quand même l'idée d'aller chercher le prof pour venir discuter avec nous puis cette idée là c'était quand même assez stressante, parce qu'on savait que c'était évaluer, de savoir qu'il fallait finir rapidement, peut-être de les étaler sur plusieurs cours ou de justement prendre le temps de le faire durer plus longtemps et pas avoir peur d'exagérer la dedant, pour s'assurer que tout le monde comprenne parce qu'il y a des filles qui mettons, il y avait des équipes ou il y avait trois qui participaient et trois que ça ne les intéressait pas et que ça montrait une dynamique moins intéressante puis que si jamais, j'ai l'impression que si on avait eu plus de temps pour parler avec le prof ça nous aurait toute aider, puis nous aurons toutes eu des cents dans les examens par rapport aux matières qui étaient abordées dans les Labotoriels.	228
				229
				230
				231
				232
12	Did the RW activities help you meet your expectations of Labatorials?	MEM18	Given that they were done before the Labatorials, well yes and no, it didn't help, it didn't help the Labatorial itself but helped the overall flow of things, and, it helped defining what I understand at first, and the Labatorial helped breaking some of them and rebuilding some of them, some of the ideas, in the success of the lab itself it didn't have any impact.	233
		MET18	I wouldn't really say so	234
		FEU28	Like examples helped the most. Q: What do you mean examples?	235

			I mean like the puck thing and the wagon dragging and if the masse is bigger, like the inertia is bigger and everything, that helped a lot, but some of the forces some of the readings I couldn't understand completely, like there were just a lot of questions that like popped out but the teacher couldn't help me, so I still didn't understand after the reading.	
		FES28	Yeah because we read about the concept, we wrote about it, and when I wrote about it, I sort of like learned about the concept more, and I and when I went to the Labatorial I would like, see the concept in act. Yeah it helped.	236
		MFJ38	Je pense que, pour moi les écritures réflexives étaient un peu moins utiles que les Labotoriels, Parce que il fallait qu'on lise les notes de cours et qu'on remet, comme les idées comme, c'était pas un résumé, c'était vraiment remettre nos idées, des exemples réels et expliquer c'était quoi dans nos propre mots sur le texte, j'ai trouvé un peu, c'était bien parce que c'était pas un résumé qu'il fallait faire, ça c'était un point que j'ai vraiment aimé, on aurait pu simplement lire les notes de cours et faire un résumé. J'ai bien aimé qu'au contraire, fallait l'expliquer nous-même et donner des vrais exemples, puis remettre en question comme les lois, pas seulement dire ah cette loi ça fait ça, parce que ça et voici la formule et c'est fini. Fallait vraiment le dire, expliquer, faire le lien avec d'autre truc pour vraiment voir si ça arrive. Q : Et ça ne t'aide pas dans les Labotoriels? Je veux dire, penser aux choses, les mettre en question, décortiquer les idées, ça t'aide pas dans les Labotoriels? Mais moyen, dans le Labotoriel je le fais vraiment, les idées que je remets, comme mettons dans les écritures réflexives je mentionne des situations de la vraie vie, dans les Labotoriels je le fais physiquement. Fait que c'est les Labotoriels qui m'aident dans les Labotoriels et les écritures réflexives c'est… Q : Mais Imagine que tu n'a pas fait l'écriture réflexive avant les Labotoriels, est-ce que tu auras fouillé dans tes idées avant ou bien non? Imagine ça, Il n'y avait pas d'écriture réflexive, tu n'a pas lu les notes de cours et tu a fait les Labotoriels. Ah non, c'est vrai, les écritures réflexives ça me permet d'avoir une base avant les Labotoriels.	237

			Q : je ne suis pas en train de te convaincre, je suis en train de te poser la question juste pour pouvoir filtrer les choses. Je pense et je réfléchis, ce n'est pas pour me convaincre. Je pense, et je fais ah oui c'est vrai, en y repensant, ça me donnait une bonne base. Arrivé dans les Labotoriels, ça m'a donné une bonne base, puis je comprenais mieux en arrivant.	
		FFL38	Je sais que les ÉR ça me faisait poser des questions, donc oui, mais je ne vois pas le, oui, oui je pense que les questions que je me posais dans les ÉR, comme j'avais dit plus tôt dans l'entrevue, j'avais dit quelque chose en rapport, je me posais des questions dans les ÉR puis je les reposait dans les Labotoriels. Mais par contre des fois, je n'ai juste pas de question pour l'ÉR puis le prof m'a dit : trouve des questions, suit ton instinct. Je ne sais pas je n'ai pas de questions. Mais comme si c'était un sujet plus intense, là j'aurai surement posé des questions. Mais en général c'est oui.	238
		FFC48	Je suis sûre qu'en quelque sorte oui ça a aidé, on a mis qu'est-ce qu'on pensait sur papier, donc on a des questions par rapport à la matière, puis quand on vient dans les Labotoriels on a l'opportunité de tester qu'est-ce qu'on pensait ou bien de voir si qu'est-ce qu'on pensait réellement, ou poser d'avantage de questions et d'en discuter d'avantage avec les membres, donc je suis sûre que ça a eu un effet, mais dans ma tête je les considère comme deux trucs différents. Je ne sais pas, pour la partie sur l'ÉR c'est beaucoup plus sur la théorie, puis les Labotoriels c'est plus sur la pratique, mais en même temps il y a quand même des liens.	239
		FFK48	Je pense que oui parce que dans les ÉR tu mets au clair où au moins tu sais comment tu penses alors dans les Labotoriels, tu peux voir si les choses que tu pensais dans les ÉR ça s'applique ou non.	240
		MES19	I think they did, like I said before, you don't know too much about the topic especially you read like one article, like now you gotta write 300 words about it and its like, often times the 300 word article, and so you have to like really think about it and give examples, and its like, one thing I enjoyed when I have a test coming up, is I like to teach someone else what I am doing on a test, like when I talk to my friends about it, it gives me like a broader	241

			understanding, and this is kinda the same thing, even if you are not talking to someone you are still writing it out.	
		FEV19	The RW? Q: Yeah when you read, and when you wrote. I think it was like a good introduction, it had us like think about the subject before, but I don't think that it had directly like helped us do better in the Labatorials. Like reading beforehand did but like the actual reflection, I don't think it helped us in the Labatorials, but it helped us think about what we actually read. Q: Had you not read and wrote would Labatorials be better or worse? I think it would be worse, but had we just read, we would not have had that much of it. Had we read and not reflected, it wouldn't have had that much of an impact, like reading beforehand is necessary, it's like going into that without knowing much.	242
		FFS49	Comme vous avez dit il y a la précompréhension, notre ER est influencée par la précompréhension donc déjà on a nos idées qui sont en tête, donc quand on arrive aux Labotoriels on sait déjà ce qu'on veut dire, on sait déjà ce qu'on veut défendre.	243
		FFD49	Je pense que ça m'a aidé, mais sans que je le sache vraiment parce que ça fixait déjà que ce que je comprenais et qu'est-ce que je ne comprenais pas et vue que tout le monde les avait fait, tout le monde savait a peu prêt ce qu'elles comprenaient ou ce qu'elles ne comprenaient pas et le fait qu'on est capable de discuter moins, comme moi je comprenais moins bien et que quelqu'un me l'expliquait pendant qu'on était en train de le faire, j'ai l'impression que cette compréhension la, mon idée de compréhension collective ca à vraiment était grâce un petit peu à l'écriture réflexive Q : donc tu dis que les Labotoriels seraient mieux avec l'ER? Oui car ça aide à la réflexion	244
				245
				246
				247
				248
	Would Labatorials be better, worse or	MEM18	As the event to itself, it would be the same, however their effect, the goal by them, by the educational system, their goal, would have been like much worst achieved it we didn't have the RW before.	249

	the same without RW?	MET18	Probably wouldn't change much. The main thing that I found about reflective writing is that it gave me like time to think about it, but I generally do that when I'm going through the papers to read, so I generally do that when I'm taking notes anyways. And the reflective writing, I felt like, I was going on tangents at a certain point through the writing, so I think I'd rather like, something like note-taking, I'd rather think for my for myself without being instructed to.	250
		FEU28	Reflective writing help us with the calculation and stuff and like some concepts with real motion but it's hard to apply directly what we read on the paper into real life, wait, wait what was the question again? Q: The question is let's take Labatorials with or without the reflective writing. Would the Labatorials be better or worse or the same without the reflective writing? I think they would be worse without the reflective writing like the readings, because you don't know anything like you don't know what to do with the free body or the object. I think they helped, but maybe like after each reading, like have the teacher explain to us.	251
		FES28	I think they would be worse, not worse, it wouldn't be as effective, I sort of like, it was annoying having to write, but at the same time it actually helped.	252
		MFJ38	Ça serait les mêmes.	253
		FFL38	Ils seraient moins bon.	254
		FFC48	Ils ne seront pas nécessairement pires, mais ça aide quand même, donc je n'enlèverai pas ça.	255
		FFK48	Les mêmes quand même, je pense, parce que, mais ça dépend parce que parfois on avait le cours avant les Labotoriels, oui? Q : Oui, parfois le cours était les Labotoriels Oui Q : Mais on a toujours fait les ÉR avant les Labotoriels. Oui, quand même, je pense oui. C'était quoi la question encore. Q : Est-ce que les Labotoriels seraient meilleurs, pires ou les mêmes sans l'ÉR? Je pense que ça serait quand même un peu plus difficile sans l'ÉR.	256
		MES19		257
		FEV19		258
		FFS49	Ils seraient pires	259
		FFD49		260

				261
				262
				263
				264
13	Do you think that physics knowledge can change? How?	MEM18	Knowledge in physics is fixed but what can change is how we perceive it due to our inability to perceive it correctly. Q: how do you think our perspective can change? Before being able to define, use words to describe the law of gravity for example, or the effect of the gravitational pull on things, the gravitational pull on things still worked exactly the same, so the physics knowledge was exactly the way it is, our understanding of it, is what changes.	265
		MET18	I think it's can, yeah. Q: How would it change? I mean like if there was a discovery made, I think it would trickle down starting with a scientific community and then they would like, come to a consensus whether this theory is true or not, and then it would trickle down to the general population through textbooks.	266
		FEU28	I think everything can change so obviously physics can change. Q: How would it change or why would it change? We can't know everything around us, it's impossible, there are so many things, we can't, and there are so many things that we haven't discovered yet. Maybe one day someone else will realize oh Newton's Laws not are entirely correct like maybe, like it's probably correct if we use it for so long, but maybe there's another part that we haven't taken account of, that might influence the entire concept of Newton's Laws for example. So obviously physics can change and I don't think it's a bad thing.	267
		FES28	Yeah Q: How? I found before these Labatorials I was like struggling more, I don't know, then after I just, I found it like more like fun. Q: the question is here, do you think that knowledge in physics can change, not your knowledge. It can change. Q: How?	268

			If people, I don't know, our teacher told us that the laws are always adjusted, and changed and like, if people discover new things, I guess.	
		MFJ38	À moins qu'il y a un évènement qu'on trouve qui est extrême et qui change complètement toutes nos lois, je ne pense pas vraiment. Q : Pas nécessairement toutes les lois. Est qu'il y a des lois qui peuvent changer en physique? Bien sûre si on découvre des trucs dans l'espace qu'on n'a pas encore découvert qui défient toutes nos, qui défient nos lois c'est sûre. Mais en général ça ne change pas vraiment. Q : ça peut ne pas être dans l'espace, l'humanité a cru pendant des siècles et de siècles, même des millénaires que le soleil tourne autour de la terre, et que la terre était plate.	269
		FFL38	Toujours, comme Albert Einstein a dit, il y a une fois un de ses élèves qui lui a demandé : mais monsieur, les questions de cet examen-là, c'est les mêmes que l'année passée. Puis il a répondu: mais les réponses cette année ont changé. Ça change toujours la physique.	270
		FFC48	Oui. Q : Comment? Si on découvre quelque chose d'autre que peut-être ça influence un certain aspect puis on ne sait jamais. En même temps qu'est-ce qu'on connait maintenant de la physique, c'est pas mal, je trouve que c'est vraiment quelque chose de sûr. Je ne sais pas comment l'expliquer, mais si jamais on peut toujours trouver une nouvelle découverte, puis ajouter d'autres. Q : Mais la découverte ne peut pas changer quelque chose qui existe déjà? Dans le futur est-ce qu'il est possible qu'une découverte ai lieu qui change quelque chose que tu connais déjà, que tu crois vrai? Je pense que oui.	271
		FFK48	Je ne prévois pas qu'ils changent, parce que pour moi, car je les ai appris comme ça faisais beaucoup de sens dans le monde, comme l'application comme on peut la voir partout. Mais aussi comme quand je pense aux sciences je pense aussi au fait comme ça change tout le temps, parce qu'on apprend des nouvelles choses, on voit des nouvelles choses. Alors, je ne suis pas sûre. Q : Donc est-ce que tu penses que les connaissances changent ou bien les connaissances ne changent pas?	272

			Elles changent. Q : Comment elles peuvent changer? Quelque chose de vraiment bizarre arrive, ça arrive mais pas selon les lois qu'on a déjà, alors on doit trouver une autre loi.	
		MES19	Yes Q: How would it change? In many ways, probably not in terms of, it's not very likely that it would change in terms of like gravity and friction, but people are constantly discovering new things in physics, people are going to space trying to find other planets, you gotta discover something that you never hear of before or like for example people used to think that you have a heavier object and a lighter object and you dropped them, the heavier one would hit first and we know that that is not true, two things have similar shapes, like if it's not a piece of paper and a pencil it was obviously going to float down.	273
		FEV19	I think it depends on what you are talking about Q; like laws, concepts… It depends what laws, I think certain laws are provable and they are like true, but then and there are other laws, which I don't know what they are, because it's like physics stuff, I think those could be probably disproven Q: ok I'm going to ask you the question again…. It depends which laws and how they were proven Q: ok, but is there a chance that they would change? Yeah Q: Let's, say somebody runs an experiment right now and discovers that something can be changed, would that change a law in physics? What do you mean? Q: I don't know let's say for now, Newton's second law, Is there a chance that they might do something and discover that no the second law was actually misunderstood, it's not right, we thought that it was that but it's something else, could that happen? Yeah, I think that science in general vary, with all the experiments you have a lot of sources of error that could come in, like a lot of it can be, like disproven. Like some of it yeah, like there are certain facts, like you can't rely on facts, on like some facts	274
		FFS49	Oui Q: comment?	275

			Je ne sais pas, si on découvre des nouvelles relations entre les choses. Selon moi on ne connait pas encore tout.	
		FFD49	Oui Q : Comment? Une découverte scientifique qui vient bousculer toute ce qu'on connait, c'est ça la science, C'est quelque chose qui change toujours	276
				277
				278
				279
				280
14	How do you evaluate yourself (objectively with respect to your classmates), in the physics course? Are you a strong, a medium or a weak student?	MEM18	In this course? In the force course or in the overall physics course? Q: Both, it's interesting, I wasn't looking for this distinction, but since you mentioned it. In the force course I am, in the middle tending toward the better students, given my performance in Labatorials, given the questions that I asked, given the performance I have on the paper, like that is supposed to define who I am. In general I would classify myself as medium to weak.	281
		MET18	Above average, on the stronger side.	282
		FEU28	I'm on the strong side, medium to strong.	283
		FES28	I think I'm like weak medium.	284
		MFJ38	Je pense que si je mettrai plus d'investissement dans l'étude et les devoirs je pourrai bien être au-dessus de la moyenne, mais là je suis moyen, peut-être un peu plus. Q : donc tu dis que tu es moyen vers le fort. Oui mais si je mettrai beaucoup plus d'effort dans mon étude et dans mes devoirs…. Q : J'en suis sûre, mais comment tu te vois maintenant? Plus que la moyenne.	285
		FFL38	Je pense que pour une question comme ça je ne peux pas répondre parce que je me dis je peux être moyenne, mais j'ai des bonnes notes parce que je suis passionné. Puis parce que je me pose des questions. Je ne suis pas un génie, mais… Q : Par rapport à tes camarades de classe, comment tu te trouves, moyenne bonne ou faible? Objectivement. Objectivement j'ai des bons résultats, parce que je me pose des questions pas parce que je suis intelligente, c'est parce que je me pose des questions.	286
		FFC48	Pas forte, moyenne.	287

		FFK48	Forte.	288
		MES19	Somewhere between strong and medium, closer to strong.	289
		FEV19	I would say medium, I'm like average.	290
		FFS49	Entre moyenne et forte.	291
		FFD49	Forte.	292
				293
				294
				295
				296
15		MEM18		297
		MET18		298
		FEU28		299
		FES28		300
		MFJ38		301
		FFL38		302
		FFC48		303
		FFK48		304
		MES19		305
		FEV19		306
		FFS49		307
		FFD49		308
				309
				310
				311
				312
16		MEM18		313
		MET18		314
		FEU28		315
		FES28		316
		MFJ38		317
		FFL38		318
		FFC48		319
		FFK48		320
		MES19		321
		FEV19		322
		FFS49		323
		FFD49		324
				325
				326
				327
				328
17		MEM18		329
		MET18		330

		FEU28		331
		FES28		332
		MFJ38		333
		FFL38		334
		FFC48		335
		FFK48		336
		MES19		337
		FEV19		338
		FFS49		339
		FFD49		340
				341
				342
				343
				344
18				345