From Naive to Scientific Understanding of Motion and its Causes

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Abstract
The difference in the descriptions of motion phenomena made by pupils in the first grades of secondary school and physicists is quite evident. Conceptual metaphors hidden in language suggest that there is continuity between the conceptual structure involved in the description and the interpretation of motion of experts and laypersons. In this paper the presence of such a continuity is shown through a metaphor analysis of linguistic expressions from both kind of people.

Keywords
physics education; language; conceptual metaphor; continuity

1. Introduction

We know from literature (DiSessa, 1993; McCloskey, Caramazza, & Green, 1980) that students face difficulties in studying motion and its causes. We argue that if we want to address this problems, we have to investigate the conceptualization of motion.
We are going to investigate the conceptual structure involved in the description of motion of laypersons, i.e. the students, and of experts, i.e. teachers, scientists, physicists. We argue that some kind of continuity should be present between these two kinds of conceptualization and that physics education should be built on it.
In the first part of this article we are going to illustrate how it is possible to understand how the concept of motion is constructed in human mind. A theory that relates mind and language is presented starting from the works of Lakoff, Johnson, Turner and Fauconnier.
In the second part we will show the analyses carried on two different sources of language, the first representing the scientific conceptualization, the second the lay one.
In the last part the evidences and the results of the analyses are presented and discussed.

2. A theory of mind

In cognitive linguistic, conceptual metaphor is defined as understanding one conceptual domain (target domain) in terms of another conceptual domain (source domain). Lakoff, Johnson and Turner underline the deep and strong connection between language and mind. According to these authors, the nature of the conceptual structure that we use to think, speak and act is figurative. As a consequence of this, conceptual metaphors play an important role in structuring knowledge. They are systematic in that there is a fixed correspondence between the structure of the domain to be understood (e.g., death) and the structure of the domain in terms of which we are understanding it (e.g., departure). We usually understand them in terms of common experiences. They are largely unconscious, though attention may be drawn to them. Their operation in cognition is almost automatic. And they are widely conventionalized in language, that is, there are a great number of words and idiomatic expressions in our language whose meanings depend upon those conceptual metaphors (Lakoff & Turner, 1989). Metaphor is no longer seen as a mere linguistic and aesthetic feature: the cognitive role of metaphor emerges in the process of structuring and acquiring new knowledge. In synthesis, a *concept* is *constituted* by the *metaphor* (Lakoff & Johnson, 1980).
Moreover, according to Fauconnier and Turner, in human mind there are entire network of projections between conceptual spaces leading to what have been known as *conceptual integration networks* (Fauconnier & Turner, 1998, 2002; Fauconnier, 1994, 1997).
As a consequence of this, we can understand the way we think, our conceptualization of motion, looking at the way we speak, in particular at the conceptual metaphors implied in the language we use to talk and to describe motion.

We have to make a distinction between metaphor and metaphoric linguistic expressions: the latter is what we hear or read when somebody uses a metaphor, the former is a figure of the mind, we might say the actual concept. We will show an example in order to evidence the difference.

Heat flows through the walls of the building

is the metaphorical expression of the metaphor:

HEAT IS A FLUID SUBSTANCE

We will use this convention in order to differentiate the conceptual metaphors from the metaphorical expressions.

3. Language analyses

In order to compare the two forms of conceptualization of motion we selected two sources of sentences about motion: the first volume of "The Feynman lectures on Physics" (Feynman, 1965) as a source of scientific language and recordings of college students enrolled in physics courses collected in the paper "Common sense concepts about motion" by Halloun and Hestenes as a source of lay language (Halloun & Hestenes, 1985).

We looked for the sentences containing the word "force" and we tried to see the underlying conceptual metaphor. We constructed the categories of conceptual metaphors in a recursive way in order to have the more general and encompassing ones. We developed the conceptual metaphors categorization starting from the Force Dynamic Gestalt theory (Fuchs, 2007), image schemas (Johnson, 1990) and event structures (Lakoff & Johnson, 1999).

Here we present the list of metaphors involved in the description of the word "force".

5. FORCE IS A SUBSTANCE-LIKE QUANTITY
    1. FORCE IS A PRODUCT
    2. FORCE IS A QUANTITY
    3. FORCE IS A POSSESSION
6. FORCE IS AN AGENT
    1. FORCE IS A COMPULSION
    2. FORCE IS A RESISTANCE
7. FORCE IS A MEDIUM
8. FORCE IS A PATH
    1. FORCE IS A LINE
    2. FORCE IS A CONNECTION
9. FORCE IS A SCALE
10. FORCE IS BALANCE

The complete list of categorized sentences is presented in the following tables (1-6). The first observation is that sentences coming from both expert and lay language are metaphorical expressions contained in all these categories.

Besides that, we also found some differences in the metaphorical expressions coming from the two sources.

Table 1. FORCE IS A SUBSTANCE-LIKE QUANTITY expressions

Conceptual metaphor sub-category	Feynman expressions	Students expressions
FORCE IS A PRODUCT	*This potentiality for producing a force is called an electric field.* *A source of the force.*	*The speed creates a force.* *The force behind it...coming from the throw.*

FORCE IS A QUANTITY	*How much force would there be?* *More or less force is required.* *There is very little force at any appreciable distance.*	*As it goes down, the force of gravity increases...and that's why the speed increases* *until [gravity] equals this amount of force.* *It provides the ball with more and more force as it goes down.*
FORCE IS A POSSESSION	*A spinning top has the same weight as a still one.* *The weight of the atom.* *These forces are within the nuclei of atoms.*	*If the mass of block X is greater than the force [of pull] of Y, block X stays in place...it could not be moved.* *[The moving body] has still got some force inside.*

FORCE IS A PRODUCT conceptual metaphor (Table 1) tells us that force could be "produced". The possible "producers" in Feynman expressions are the basic interactions between objects, i.e. electrical and gravitational, while in students expressions the "producers" are speed and aspects of motion.
In FORCE IS A QUANTITY metaphorical expressions (Table 1), Feynman only speaks about the intensity of force, while in students' language we find expressions that are related to the concept of momentum or energy of a moving object.
Finally, the metaphorical expressions of FORCE IS A POSSESSION (Table 1) in Feynman are only about weight, while in laypersons we have expressions involving moving objects, devices that produce movement (i.e. a cannon), and more abstract concepts as power, inertia and velocity.

Table 2. FORCE IS AN AGENT expressions

Conceptual metaphor sub-category	Feynman expressions	Students expressions
(unsorted)	*The first charge will feel a certain reaction force.*	*There is not a force [acting on] on the ball.* *Gravity means the same force pulls on different objects.*
FORCE IS A COMPULSION	*Because of the action of a force, the velocity changes.* *The force which controls, let us say, Jupiter in going around the sun.*	*A force only starts the motion.* *A force is just changing the direction of motion.*
FORCE IS A RESISTANCE	*It is a question of electrical forces against which we are working.* *No tangential force is needed to keep a planet in its orbit.*	*A force has nothing to do with the speed, it only has to keep the ball moving.*

Table 3. FORCE IS MEDIUM expressions

Feynman expressions	Students expressions
We shall have to hold the piston down by a certain force. *The gas exerts a jittery force.*	*That maximum speed is always equal to the force you apply.*

Table 4. FORCE IS A PATH expressions

Conceptual metaphor sub-category	Feynman expressions	Students expressions

FORCE IS A LINE	*The force in the vertical direction due to gravity.* *The force is directed along the line joining the planet to the sun.*	*The ball goes out in the direction of the resultant [of the forces].*
FORCE IS A CONNECTION	*The true nature of the forces between the atoms.*	none

Table 5. FORCE IS A SCALE expressions

Feynman expressions	Students expressions
The force weakens as we go higher. *The more massive a thing is, the stronger the force required to produce a given acceleration.*	none

Table 6. FORCE IS BALANCE expressions

Feynman expressions	Students expressions
If the force between them were not balanced. *Talk only about excess forces.* *All the internal forces will balance out.*	none

Some metaphorical expressions found in Feynman are not present in students expressions, but we think this could be due to the set of data chosen for this purpose. We are almost sure that similar sentences could be found in students expressions if only we could have a larger collection.
The metaphorical sentences in lay language often involved the terms “speed” or “velocity”. In order to deepen our investigations we repeated the same analysis for the sentences containing these two words.
The conceptual metaphors we found are listed below.

- SPEED IS A SUBSTANCE
  - SPEED IS A POSSESSION
  - SPEED IS A QUANTITY
- SPEED IS A LOCATION
  - SPEED IS A LEVEL
  - SPEED IS A SCALE
- SPEED IS AN AGENT
  - SPEED IS A FORCE
  - SPEED IS A MAKER

Table 7 collects the categorization of the metaphorical sentences found in both set of data.

Table 7. Speed and Velocity metaphors and metaphorical expressions

Conceptual metaphor category	Conceptual metaphor sub-category	Feynman expressions	Students expressions
SPEED IS A SUBSTANCE	SPEED IS A POSSESSION	*Motion of a body.* *If she kept going with the same speed.* *The velocity of the falling ball.*	*Its speed remains constant.* *Their speed gets greater and greater.* *Both should have the same speed.*
	SPEED IS A QUANTITY	*[...] if we increase the speed of the atoms.*	*Its velocity keeps increasing.* *The speed is smaller.* *A new speed bigger than the one it had before.*
SPEED IS A LOCATION	SPEED IS A LEVEL	*At what speed is the radius increasing?* *She is going at that speed.* *Some car can get from rest to 60 miles an hour.*	*The ball must go at constant speed.* *They can reach a speed limit.*
	SPEED IS A SCALE	*It speeds up.* *The car was slowing down.* *High speeds.*	*It speeds up for a short while.* *It slows down.*
SPEED IS AN AGENT	SPEED IS A FORCE	none	*The force due to the air overcomes the initial velocity.* *The force of velocity.*
	SPEED IS A MAKER	none	*The speed creates a force.*

All the expressions belonging from the two sources fitted all these categories with only one exception. Metaphorical expressions belonging to SPEED IS AN AGENT can only be found in students language.

4. Results and conclusions

This metaphor analysis is a powerful and sensible tool that allows us to investigate the conceptual structure that both scientists and students use to understand and to explain phenomena.

The first important result is that the metaphorical expressions coming from both lay and expert language share the majority of the metaphors. This allows us to claim that there is continuity between the two kind of language.

We also revealed a metaphorical and conceptual mismatch involving velocity and speed. In the analysis we discovered that SPEED IS AN AGENT is a conceptual metaphor only present in lay language (students). Therefore we could say that speed (and velocity) is perceived and conceptualized as an agent only by laypersons (students), while this is not true for scientists and experts (Feynman).

Another important result is that some aspects coming from the Force Dynamic Gestalt theory, such as quantity, quality, intensity (Fuchs, 2007) are present in the metaphorical expressions. Moreover they are not completely differentiated in lay language.

The presence of continuity tells us that it is possible to teach starting from the knowledge pupils have already developed during their previous experiences: we could use conceptual metaphor as a basis for developing a physics curriculum.

Physics teachers should be aware of the conceptual metaphors and how they relates and overlap in order to create comprehension (i.e. conceptual integration networks). In this sense we could say that an education based on conceptual metaphors could help students to be aware of them in order to understand and relate the aspects involved in the interpretation of motion and its causes.

In order to do so further analysis should be done in order to reveal the logical connections and the dependencies between concepts involved in the description of motion (momentum, energy). A refined analysis should be done taking different language sources, both oral and written.

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TEACHING/LEARNING PHYSICS: INTEGRATING RESEARCH INTO PRACTICE

EDITORS

Claudio Fazio and Rosa Maria Sperandeo Mineo



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Table of contents

Preface 1
Rosa Maria Sperandeo-Mineo and Claudio Fazio

1. General Talk Papers

CONSIDERING PHYSICS KNOWLEDGE AS A CULTURE. AN APPROACH TO PHYSICS CURRICULUM MATCHING INTERESTS AND NEEDS OF CONTEMPORARY LEARNERS 5
Igal Galili

HOW CAN THE LEARNING OF PHYSICS SUPPORT THE CONSTRUCTION OF STUDENTS' PERSONAL IDENTITIES? 19
Olivia Levrini

RESEARCH-BASED INTERACTIVE SIMULATIONS TO SUPPORT QUANTUM MECHANICS LEARNING AND TEACHING 29
Antje Kohnle

SUPPORTING TEACHERS USE AND ASSESSMENT OF INQUIRY BASED SCIENCE EDUCATION IN CLASSROOM PRACTICE 41
Eilish Mcloughlin, Odilla Finlayson

POTENTIALLY MEANINGFUL TEACHING UNITS (PMTUS) IN PHYSICS EDUCATION 47
Marco Antonio Moreira

THINKING THE CONTENT FOR PHYSICS EDUCATION RESEARCH AND PRACTICE 61
Laurence Viennot

2. Physics Teaching/Learning at Primary Level and Teacher Education

TEACHING ABOUT ENERGY USING COOPERATIVE LEARNING: AN IMPLEMENTATION AND ITS EVALUATION IN A TEACHER TRAINING DEGREE 83
Arantza Rico

EARLY CHILDHOOD SCIENCE EDUCATION IN AN INFORMAL LEARNING ENVIRONMENT 91
Enrica Giordano, Sabrina Rossi

USING VIDEOS AND VIDEO EDITING SOFTWARE WITH PRE-SERVICE TEACHERS FOR OUR MODERN PRIMARY SCIENCE CLASSROOMS 99
Maeve Liston

METHODS BASED ON NON-FORMAL-LEARNING AND EMOTION-BASED LEARNING FOR TEACHING PHYSICS IN PRIMARY AND LOWER SECONDARY SCHOOLS 109
Silvia Merlino, Rosaria Evangelista, Carlo Mantovani

THE PERSISTENCE OF THE ALTERNATIVE CONCEPTIONS: THE CASE OF THE UNIPOLAR MODEL 117
Abdeljalil Métioui, Louis Trudel

THE ROLE OF SCIENTIFIC MUSEUMS IN PHYSICS AND ASTRONOMY EDUCATION COURSES FOR PRE-SERVICE PRIMARY SCHOOL TEACHERS 129
Ornella Pantano, Sofia Talas, Valeria Zanini

THE EDUCATION OF PRE-SERVICE PRIMARY SCHOOL TEACHERS FOR TEACHING PHYSICS AS PART OF THE SCIENCE CURRICULUM IN SLOVENIA 137
Jerneja Pavlin, Mojca Čepič

3. Physics Teaching and Learning at Secondary Level

PROBABILITY AND AMOUNT OF DATA 149
Corrado E. Agnes

FROM NAÏVE TO SCIENTIFIC UNDERSTANDING OF MOTION AND ITS CAUSES 157
Alessandro Ascari, Federico Corni, Gabriele Ceroni, Hans U. Fuchs

HIGH SCHOOL STUDENTS FACE THE MAGNETIC VECTOR POTENTIAL: SOME RELAPSES IN THEIR LEARNING AND TIPS FOR TEACHERS DEALING WITH ELECTROMAGNETISM 165
Sara R. Barbieri, Marco Giliberti

RESPONSIBLE RESEARCH AND INNOVATION IN SCIENCE EDUCATION: THE IRRESISTIBLE PROJECT 175
Eugenio Bertozzi, Claudio Fazio, Michele Antonio Floriano, Olivia Levrini, Roberta Maniaci, Barbara Pecori, Margherita Venturi, Jan Apotheker

WORKSHOP: TIPS AND TRICKS TO MAKE TRADITIONAL LABORATORY MORE MINDS-ON AND INQUIRY 183
Ed van den Berg

PLAYING WITH (SUPER)HYDROPHOBICITY: AN INTERDISCIPLINARY EXPERIMENTAL SEQUENCE ON PHYSICAL PROPERTIES OF WATER 193
Assunta Bonanno, Giacomo Bozzo, Federica Napoli, Peppino Sapia

EXPLAINING PHENOMENA SCIENTIFICALLY AND IDENTIFYING SCIENTIFIC ISSUES IN PHYSICS EDUCATION: SOME INTERESTING OBSERVATIONS OF THE HIGH-PERFORMING ECONOMIES IN PISA 2006 201
Kwok-cheung Cheung

A DYNAMICAL MODEL FOR THE ROLLING CYLINDER 209
Michele D'Anna

AN ALTERNATIVE APPROACH TO THE BOLTZMANN DISTRIBUTION THROUGH THE CHEMICAL POTENTIAL 217
Michele D'Anna, Georg Job

IMPLEMENTATION OF A PROPOSAL TO TEACH QUANTUM MECHANICS CONCEPTS FROM FEYNMAN'S MULTIPLE PATHS APPLIED TO THE LIGHT 225
María De Los Angeles Fanaro, María Rita Otero, Mariana Elgue

SECONDARY STUDENTS' VIEWS ABOUT SCIENTIFIC INQUIRY 233
Silvia Galano, Alessandro Zappia, Luigi Smaldone, Italo Testa

DEVELOPMENT OF TEACHING MATERIALS: A COURSE FOR GEOMETRICAL OPTICS FOR LOWER SECONDARY STUDENTS 241
Claudia Haagen, Martin Hopf

SIMPLE EXPERIMENTS SUPPORTING CONCEPTUAL UNDERSTANDING OF BODY COLOUR 249
Claudia Haagen

A SUPERFICIAL TEXTBOOK PRESENTATION OF THE GENEVA LAKE EXPERIMENT FOR MEASURING SOUND SPEED IN WATER: STUDENTS' CONSIDERATIONS OF COHERENCE BETWEEN TEXTUAL AND VISUAL INFORMATION 257
Zalkida Hadzibegovic, Josip Slisko

ON THE VERDICT OF THE GERMAN PHYSICAL SOCIETY AGAINST THE *KARLSRUHE PHYSICS COURSE* – A CHRONICLE OF EVENTS 267
Friedrich Herrmann, Michael Pohlig

THERMOLAB - SIMULATING THERMAL PROCESSES BY SIMULATING GIBBS ENSEMBLES 275
Oliver Frisius, Friedrich Herrmann, Michael Pohlig,

HOW SECONDARY SCHOOL STUDENTS CONCEPTUALIZE INFRARED RADIATION - MATTER INTERACTION? FINDINGS FROM A RESEARCH STUDY AND IMPLICATIONS FOR AN INSTRUCTIONAL DESIGN 281
María Isabel Hernández, Raquel Ríos, Roser Pintó

IS IT DIFFICULT TO MOTIVATE OUR STUDENTS TO STUDY PHYSICS? 289
Renata Holubova

STUDENTS' MISCONCEPTIONS REGARDING EVERYDAY THERMAL PHENOMENA 297
Petr Kácovský

A PLATFORM TO SUPPORT CO_2 EMISSIONS MAPPING ON THE AEGEAN SEA ISLANDS 305
Barbara Kasselouri, Harry Kambezidis, Alexis Kaselouris, Dimitrios Zevgolis

PHYSICS TEACHERS' INVENTIONS FAIR – CONFERENCE AND SOURCE OF TEACHING IDEAS 319
Zdeňka Koupilová, Leoš Dvořák

HIGH SCHOOL STUDENTS´ MISCONCEPTIONS IN ELECTRICITY AND MAGNETISM AND SOME EXPERIMENTS THAT CAN HELP TO REDUCE THEM 323
Vera Koudelkova, Leos Dvorak

KINEMATICS CONCEPTS AT DIFFERENT REPRESENTATION LEVELS – A MUTUAL INFORMATION APPROACH 329
Clemens Wagner, Andreas Lichtenberger, Andreas Vaterlaus

GUIDING STUDENTS TO COMBINE PARTIAL LAWS OF ENERGY CONSERVATION 339
Paul S. W. M. Logman, Wolter H. Kaper and Ton L. Ellermeijer

A NEW PHYSICS CURRICULUM FOR A VOCATIONAL SCHOOL 347
Vera Montalbano, Roberto Benedetti, Emilio Mariotti

TEACHING THE BASIC CONCEPTS OF THE SPECIAL RELATIVITY IN THE SECONDARY SCHOOL IN THE FRAMEWORK OF THE THEORY OF CONCEPTUAL FIELDS OF VERGNAUD 355

Maria Rita Otero, Marcelo Arlego, Fabiana Prodanoff

TEACHERS' VIEWS ABOUT THE IMPLEMENTATION OF AN INTEGRATED SCIENCE CURRICULUM 367
Valeria Poggi, Italo Testa, Cristina Miceli

VACUUM: ITS MEANING AND ITS EFFECTS THROUGHOUT EXPERIMENTAL ACTIVITIES 373
Marta Rinaudo, Daniela Marocchi, Antonio Amoroso

DETERMINATION OF THE EARTH RADIUS BY MEASURING THE ANGULAR HEIGHT OF THE SUN ABOVE HORIZON 379
Alexander Kaplinsky, Konstantin Rogozin, Alexey Sorokin, Darya Shakhvorostova, Alexander Wolf

IMPLEMENTATION OF PEER INSTRUCTION IN CZECH SCHOOLS 383
Jana Šestáková

HOW DOES EPISTEMOLOGICAL KNOWLEDGE ON MODELLING INFLUENCE STUDENTS' ENGAGEMENT IN THE ISSUE OF CLIMATE CHANGE? 387
Giulia Tasquier

AN OPEN INQUIRY RESEARCH-BASED TEACHING-LEARNING SEQUENCE ABOUT THE CAUSE OF SEASONS 399
Italo Testa, Gianni Busarello, Silvio Leccia, Emanuella Puddu, Arturo Colantonio

IMPACT OF A DISCUSSION METHOD ON HIGH SCHOOL STUDENTS' UNDERSTANDING OF KINEMATICAL CONCEPTS 407
Louis Trudel, Abdeljalil Métioui

4. Physics Teaching and Learning at University Level

THE BRACED STRING, DISPERSION AND POLARIZATION 421
Sergej Faletič

HOW CLOSE CAN WE GET WAVES TO WAVEFUNCTIONS, INCLUDING POTENTIAL? 429
Sergej Faletič

HOW CAN FUTURE EUROPEAN PHYSICS STUDIES LEAD TO INNOVATIVE COMPETENCES AND STIMULATE ENTREPRENEURIAL BEHAVIOUR? 437
Hendrik Ferdinande

INVESTIGATING PHYSICS TEACHING AND LEARNING AT UNIVERSITY 443
Jenaro Guisasola, Mieke De Cock, Stephen Kanim, Lana Ivanjek, Kristina Zuza, Laurens Bollen, Paul Van Kampen

VIDEO ANALYSIS BASED TASKS IN PHYSICS 453
Peter Hockicko, Katarína Pažická

IMPROVING STUDENTS' UNDERSTANDING BY USING ONGOING EDUCATION RESEARCH TO REFINE ACTIVE LEARNING ACTIVITIES IN A FIRST-YEAR ELECTRONICS COURSE 461
Alexander P. Mazzolini, Scott A. Daniel

TEACHING ELECTROSTATICS THROUGH PROJECT-BASED LEARNING 469
Carlos Collazos, Cesar Mora, Ricardo Otero, Jaime Isaza

MULTIPLE BOUNCES OF DIFFERENT MATERIAL BALLS IN FREE FALL 477
Armando C. Perez Guerrero Noyola, Fernando Yañez Barona

AN INQUIRY-BASED APPROACH TO THE FRANCK-HERTZ EXPERIMENT 485
Dominique Persano Adorno, Nicola Pizzolato

PHYSICAL MODELLING: A DIFFERENT APPROACH TO TEACH NON-PHYSICS MAJORS 493
Estela M. Puente Leos, Marcos Ley Koo

THE NATURE OF STUDENTS' REASONING PROCESSES IN TASKS INVOLVING THE CONCEPT OF ANGULAR ACCELERATION 499
Graham Rankin

ACTIVE LEARNING IN OPTICS: A WORKSHOP 503
David R. Sokoloff

EVALUATION FOR UNDERGRADUATE PROGRAMS: THE CASE OF THE BS APPLIED PHYSICS IN THE UNIVERSITY OF SAN CARLOS 515
Cherile Obate- Yap, Enriqueta D. Reston

INVESTIGATING STUDENT IDEAS ON THE CONNECTION BETWEEN FORMAL STRUCTURES AND CONCEPTUAL ASPECTS IN QUANTUM MECHANICS 523
Giacomo Zuccarini, Marisa Michelini

5. ICT and Multi-Media in Physics Education

OPERATING SYSTEM INDEPENDENT PHYSICS SIMULATIONS 533
Osvaldo Aquines, Hector Gonzalez, Pablo Perez

INTERACTIVE WHITEBOARD (IWB) AND CLASSROOM RESPONSE SYSTEM (CRS): HOW CAN TEACHERS USE THESE RESOURCES? 539
Assunta Bonanno, Giacomo Bozzo, Federica Napoli, Peppino Sapia

THE USES OF INTERACTIVE WHITEBOARD IN A SCIENCE LABORATORY 551
Giacomo Bozzo, Carme Grimalt-Alvaro, Víctor López

PREPARING PRE-SERVICE TEACHERS TO INTEGRATE TECHNOLOGY INTO INQUIRY-BASED SCIENCE EDUCATION: THREE CASE STUDIES IN THE NETHERLANDS 559
Trinh-Ba Tran, Ed van den Berg, Ton Ellermeijer, Jos Beishuizwen

LEARNING ASSESSMENT ABOUT THE MOON´S SYNCHRONOUS ROTATION MEDIATED COMPUTATIONAL RESOURCE 575
Adriano L. Fagundes, Tatiana da Silva,Marta Feijó Barroso

USING TECHNOLOGY TO PROVIDE AN INTERACTIVE LEARNING EXPERIENCE 583
Kyle Forinash, Raymond Wisman

USE YOUR HEAD - IN FOOTBALL AND IN PHYSICS EDUCATION 591
Angela Fösel, Leopold Mathelitsch, Sigrid Thaller, Jens Wagner

FORMATION OF KEY COMPETENCIES THROUGH INFORMATION AND COMMUNICATION TECHNOLOGY 601
Tomasz Greczylo, Ewa Dębowska

COMPARING METHODS OF MEASUREMENT OF FRICTION WITH SIMPLE EQUIPMENT AND WITH DATA-LOGGERS 609
Kamila Hrabovská, Libor Koníček, Libuše Švecová, Karla Barčová

IMPLEMENTATION OF AN IN-SERVICE COURSE ON INTEGRATION OF ICT INTO INQUIRY BASED SCIENCE EDUCATION: A CASE STUDY IN SLOVAKIA 617
Zuzana Ješková, Trinh-Ba Tran, Marián Kireš and Ton Ellermeijer

iMOBILE PHYSICS: A RESEARCH AND DEVELOPMENT PROJECT FOR TEACHING AND LEARNING WITH SMARTPHONES AND TABLET PCS AS MOBILE EXPERIMENTAL TOOLS 629
Pascal Klein, Jochen Kuhn, Andreas Müller

WHAT IS LIGHT? FROM OPTICS TO QUANTUM PHYSICS THROUGH THE SUM OVER PATHS APPROACH 639
Massimiliano Malgieri, Pasquale Onorato, Anna De Ambrosis

REPORT AND RECOMMENDATIONS ON MULTIMEDIA MATERIALS FOR TEACHING AND LEARNING QUANTUM PHYSICS 647
Bruce Mason, Ewa Dębowska, Tanwa Arpornthip, Raimund Girwidz, Tomasz Greczyło, Antje Kohnle, Trevor Melder, Marisa Michelini, Lorenzo Santi, Jorge Silva

CHAOTIC BEHAVIOUR OF ZEEMAN MACHINES AT INTRODUCTORY COURSE OF MECHANICS 657
Péter Nagy, Péter Tasnádi

ASSESSMENT OF STUDENT CONSTRUCTED MODELS ON TOPICS RELEVANT TO HEAT AND TEMPERATURE SYSTEMS 667
Christiana Th. Nicolaou, Bert Bredeweg, Constantinos P. Constantinou, Jochem Liem

ROLLING MOTION: EXPERIMENTS AND SIMULATIONS FOCUSING ON SLIDING FRICTION FORCES 675
Pasquale Onorato, Massimiliano Malgieri, Anna De Ambrosis

TEACHING OPTICS WITH A VIRTUAL MACH-ZEHNDER INTERFEROMETER: AN ANALYSIS OF A COLLABORATIVE LEARNING ACTIVITY 683
Alexsandro Pereira de Pereira, Fernanda Ostermann

USING LEARNING MANAGEMENT SYSTEM TO INTEGRATE PHYSICS COURSES WITH ONLINE ACTIVITIES: A CASE STUDY 691
Edlira Prenjasi, Shpresa Ahmetaga

DESIGN, TRAINING EXERCISES AND FEEDBACK IN AN ONLINE LEARNING ENVIRONMENT ABOUT ELECTRONS IN ELECTRIC AND MAGNETIC FIELDS 697
Stefan Richtberg, Raimund Girwidz

REMOTE AND VIRTUAL LABORATORIES AS PART OF ONLINE COURSES 705
Konstantin Rogozin, František Lustig, Sergey Kuznetsov, Denis Yanyshev, Pavel Brom, Maxim Kiryasov, Alexey Ovcharov

ON-LINE COURSEWORK FOR STUDENTS OF OPTICS 711
Konstantin Rogozin, Sergey Kuznetsov, Irina Rogozina, Denis Yanyshev, Vesselina Dimitrova, Nadezhda Isaeva, Ekaterina Sorokina

DESIGNING AN EDUCATIONAL METHODOLOGY TO TEACHING THERMAL EQUILIBRIUM USING ICT 719
Rubén Sánchez Sánchez

THE PHOTOELECTRIC EFFECT AND STUDY OF THE DIFFRACTION OF LIGHT: TWO NEW EXPERIMENTS IN UNILABS VIRTUAL AND REMOTE LABORATORIES NETWORK 727
Juan P. Sánchez, Jacobo Sáenz, Luis de la Torre, Carmen Carreras, Manuel Yuste, Rubén Heradio , Sebastián Dormido

TRAINING AND ASSESSMENT OF EXPERIMENTAL COMPETENCIES FROM A DISTANCE: OPTICAL SPECTROMETRY VIA THE INTERNET 733
Lars-Jochen Thoms, Raimund Girwidz

PERFORMANCE TASK USING VIDEO ANALYSIS AND MODELLING TO PROMOTE K12 EIGHT PRACTICES OF SCIENCE 743
Loo Kang Wee, Tze Kwang Leong

6. In-service and Pre-service Teacher Education

PROJECT BASED LEARNING FOR TEACHER EDUCATION IN BRAZIL'S STATE WITH THE LOWEST LITERACY RATE 753
Marcos H. Abreu de Oliveira, Mara F. Parisoto, Robert Fischer

THE EUROPEAN TEMI PROJECT INVOLVES ITALIAN TEACHERS: FIRST OUTCOMES 759
Sara R. Barbieri, Marina Carpineti, Marco Giliberti

INTERACTIVE METHODOLOGIES IN PHYSICS TEACHER TRAINING OF IN A CONTEXT OF CURRICULUM INNOVATION: THE PEER INSTRUCTION METHOD 767
Marcelo A. Barros and Marina V. Barros

HOW EXPERIMENTAL RESOURCES IN PHYSICS TEACHING FACILITATE CONCEPTUAL LEARNING? 775
Carlos Buitrago, Maria M. Andrés

INERTIAL AND NON-INERTIAL FRAMES: WITH PIECES OF PAPER AND IN AN ACTIVE WAY 783
Leos Dvorak

"ELIXIR FOR SCHOOLS" – A NEW INITIATIVE SUPPORTING CZECH PHYSICS TEACHERS 791
Irena Dvorakova, Leos Dvorak

EFFECTS OF GENDER AND TEACHING PRACTICE IN AN OUT-OF-SCHOOL LEARNING LAB ON ACADEMIC SELF-CONCEPT OF PRE-SERVICE PHYSICS TEACHERS 795
Markus Elsholz, Susan Fried, Thomas Trefzger

REVISITING DERIVATIVES IN PHYSICS WITH PRE-SERVICE PHYSICS TEACHERS IN K-12 CLASSES 803
Olga Gioka

IN-SERVICE AND PRE-SERVICE TEACHER EDUCATION IN IBSE – THE ESTABLISH APPROACH 811
Zuzana Ješková, Marián Kireš, Eilish McLoughlin, Odilla Finlayson, Christina Ottander, Margareta Ekborg

THE INFLUENCE OF MATHEMATICAL REPRESENTATIONS ON STUDENTS' CONCEPTUALIZATIONS OF THE ELECTROSTATIC FIELD 819
Ricardo Karam, Terhi Mäntylä

UNDERSTANDING AND EXPLAINING EQUATIONS FOR PHYSICS TEACHING 827
Ricardo Karam, Olaf Krey

INVESTIGATION OF A REFLECTIVE PEDAGOGY TO ENCOURAGE PRE-SERVICE PHYSICS TEACHERS TO EXPLORE ARGUMENTATION AS AN AID TO CONCEPTUAL UNDERSTANDING 835
Greg Lancaster, Rebecca Cooper

TOWARDS A PCK OF PHYSICS AND MATHEMATICS INTERPLAY 843
Yaron Lehavi, Esther Bagno, Bat-Sheva Eylon, Roni Mualem, Gesche Pospiech, Ulrike Böhm, Olaf Krey, Ricardo Karam

RESEARCH BASED ACTIVITIES IN TEACHER PROFESSIONAL DEVELOPMENT ON OPTICS 853
Marisa Michelini, Alberto Stefanel

EXPLORING SLIDING FRICTION: AN INQUIRY-BASED EXPERIENCE FOR PRE-SERVICE SCIENCE TEACHERS 863
Vera Montalbano

WAVE-PARTICLE COMPLEMENTARITY: TEACHING QUANTUM PHYSICS WITH A VIRTUAL MACH-ZEHNDER INTERFEROMETER 871
Jader da Silva Neto, Cláudio José H. Cavalcanti, Fernanda Ostermann

THE PROFILES APPROACH TO TEACHING AND LEARNING PHYSICS IN SLOVENIA 879
Jerneja Pavlin, Iztok Devetak

THE ROLE OF MATHEMATICS FOR PHYSICS TEACHING AND UNDERSTANDING 889
Gesche Pospiech, BatSheva Eylon, Esther Bagno, Yaron Lehavi, Marie-Annette Geyer

SCIENCE TEACHERS' TRANSFORMATIONS WHEN IMPLEMENTING INQUIRY-BASED TEACHING-LEARNING SEQUENCES 897

Alessandro Zappia, Silvia Galano, Luigi Smaldone, Italo Testa

TEACHER AND PROFESSIONAL DEVELOPMENT IN IBSE AND ASSESSMENT 907
Marián Kireš, Zuzana Ješková, Eilish McLoughlin, Odilla Finlayson, Margareta Ekborg, Christina Ottander

7. Physics Teaching and Learning in Informal Settings

DEVELOPMENT OF STUDENTS´ INTEREST IN PARTICLE PHYSICS AS EFFECT OF PARTICIPATING IN A MASTERCLASS 915
Kerstin Gedigk, Gesche Pospiech

"GOOD VIBRATIONS" - A WORKSHOP ON OSCILLATIONS AND NORMAL MODES 923
Sara R. Barbieri, Marina Carpineti, Marco Giliberti, Enrico Rigon, Marco Stellato, Marina Tamborini

CHAOS THEORY AND ITS MANIFESTATIONS: AN INFORMAL EDUCATIONAL ACTIVITY TO EXPLAIN CHAOS TO STUDENTS 931
Valeria Greco, Salvatore Spagnolo

MULTIMEDIA SOFTWARE “ARCHIMEDES AND HIS WORK”: A DEEPENING PATH IN THE ARKIMEDEION MUSEUM OF SIRACUSA 937
Silvia Merlino, Marco Bianucci, Carlo Mantovani, Roberto Fieschi

PHYSICS COMPETITIONS FOR LEARNERS OF PRIMARY SCHOOLS IN SLOVENIA 949
Barbara Rovšek, Robert Repnik

A SINGING WINE GLASS AS AN INSTRUMENT FOR TEACHING ACOUSTICS 955
José A. Zárate Colin, Marisol Rodríguez Arcos, Karina Ramos Musalem, Estela M. Puente Leos, Marcos Ley Koo

INFORMAL TEACHING OF PHYSICS AT A HUNGARIAN SCIENCE CENTER 965
Péter Mészáros

8. History and Philosophy of Science in Physics Education

RECASTING PARTICLE PHYSICS BY ENTANGLING PHYSICS, HISTORY AND PHILOSOPHY 973
Eugenio Bertozzi, Olivia Levrini

THE DISCOVERY OF X-RAYS DIFFRACTION: FROM CRYSTALS TO DNA. A CASE-STUDY TO PROMOTE UNDERSTANDING OF THE NATURE OF SCIENCE AND OF ITS INTERDISCIPLINARY CHARACTER 979
Francesco Guerra, Matteo Leone, Nadia Robotti

A TEACHING PROPOSAL ON ELECTROSTATICS BASED ON THE HISTORY OF SCIENCE THROUGH THE READING OF HISTORICAL TEXTS AND ARGUMENTATIVE DISCUSSIONS 987
Marina Castells, Aikaterini Konstantinidou, Josep Maria Cerveró

NATURE OF SCIENCE IN SCIENCE EDUCATION: FROM ‘TENETS’ TO ‘THEMES’ 999
Andre F. Pinto Martins, Jim Ryder

9. Pedagogical Methods and Strategies

THE ROLE OF TEACHING SCAFFOLDING IN INQUIRY-BASED LEARNING OF BLACK-BOXED ELECTRIC CIRCUITS 1011
Wheijen Chang

INTEGRATED STEM IN SECONDARY EDUCATION: A CASE STUDY 1021
Jolien De Meester, Heidi Knipprath**,** Jan Thielemans, Mieke De Cock, Greet Langie, Wim Dehaene

A QUANTITATIVE METHOD TO ANALYSE AN OPEN ANSWER QUESTIONNAIRE: A CASE STUDY ABOUT THE BOLTZMANN FACTOR 1029
Onofrio R. Battaglia, Benedetto Di Paola

AN AMERICAN INSTRUCTOR IN AN UPPER-LEVEL ITALIAN PHYSICS CLASS 1041
Gerald Feldman

TEACHER CHANGE IN IMPLEMENTING A RESEARCH DEVELOPED REPRESENTATION CONSTRUCTION PEDAGOGY 1049
Peter Hubber, Gail Chittleborough

LABORATORY ACTIVITIES AND THE PERCEPTION OF STUDENTS 1059
Daniela Marocchi, Marina Serio

MATHEMATICAL MODEL OF THE DIDACTIC STRUCTURE OF PHYSICS KNOWLEDGE EMBODIED IN PHYSICS TEXTBOOKS 1071
Eizo Ohno

INFLUENCE OF PEER METHOD AND IBSE IN SCIENCE COMPETENCE IN CHILEAN SECONDARY STUDENTS 1079
Nataly Rodríguez, Iván Sánchez, Ivo Fustos

SOLVING OF QUANTITATIVE PHYSICS TASKS – SELECTED SUB-SKILLS AND HOW TO 1087

TEACH THEM
Marie Snetinova, Zdeňka Koupilová,

USING ROLE-PLAYING GAME IN A VIRTUAL LEARNING ENVIRONMENT FOR A NEW APPROACH TO PHYSICS CLASSROOM LESSONS 1095
Annalisa Terracina, Massimo Mecella

List of Referees 1105

Author Index 1107

Preface

The GIREP-MPTL International conference on Teaching/Learning Physics: Integrating Research into Practice [GIREP-MPTL 2014] was held . from 7 to 12 July 2014, at the University of Palermo, Italy.

The conference has been organised by the Groupe International de Recherche sur l'Enseignement de la Physique [GIREP] and the Multimedia in Physics Teaching and Learning [MPTL] group and it has been sponsored by the International Commission on Physics Education [ICPE] – Commission 14 of the International Union for Pure and Applied Physics [IUPAP], the European Physical Society – Physics Education Division [EPS-PED], the Latin American Physics Education Network [LAPEN] and the Società Italiana di Fisica [SIF].

The theme of the conference, **Teaching/Learning Physics: Integrating Research into Practice**, underlines aspects of great relevance in contemporary science education. In fact, during the last few years, evidence based Physics Education Research provided results concerning the ways and strategies to improve student conceptual understanding, interest in Physics, epistemological awareness and insights for the construction of a scientific citizenship. However, Physics teaching practice seems resistant to adopting adapting these findings to their own situation and new research based curricula find difficulty in affirming and spread, both at school and university levels. The conference offered an opportunity for in-depth discussions of this apparently wide-spread tension in order to find ways to do better.

The purpose of the GIREP-MPTL 2014 was to bring together people working in physics education research and in physics education at schools from all over the world to allow them to share research results and exchange their experience.

About 300 teachers, educators, and researchers, from all continents and 45 countries have attended the Conference contributing with 177 oral presentations, 15 workshops, 11 symposia, and around 60 poster presentations, together with 11 keynote addresses (general talks).

After the conference, 147 papers have been submitted for the GIREP-MPTL 2014 International Conference proceedings. Each paper has been reviewed by at least two reviewers, from countries that are different to those of the authors and on the basis of criteria described on the Conference web site. Papers were subsequently revised by authors according to reviewers' comments and the accepted papers are reported in this book, divided in 8 Sections on the basis of the keywords suggested by authors. The other book section (actually, the first one) contains the papers that six of the keynote talkers sent for publication in this Proceedings Book.

We would like to thank all the authors that contributed with their papers to the realization of this book and all the referees that with their criticism helped authors to improve the quality of the papers.

Palermo, 30th June 2015 Rosa Maria Sperandeo Mineo and Claudio Fazio