

# **TEACHING AND LEARNING ABOUT ELECTROMAGNETISM IN HIGH SCHOOL: ADDRESSING ISSUES OF RELEVANCE AND EPISTEMIC PRACTICE**

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## **ABSTRACT**

Electromagnetism presents an interesting topic for teaching and learning of physics in high school. On the one hand, the corresponding phenomena are mostly outside the range of student experiences and relevance to every day life is not immediately identifiable for many. On the other hand, the topic offers a rich context for cultivating conceptual understanding of a progression of core scientific concepts such as interaction at a distance, force fields, mesoscopic structural models and induction. We have taken up these challenges with a view to explore the extent to which we could use epistemic practices in science and technology as an innovative approach to highlighting the relevance of electromagnetic phenomena and engaging students in a process of inquiry oriented teaching and learning. To achieve this, we have combined principles from the inquiry-oriented teaching and learning framework and learning through technological design in order to design a teaching learning sequence of activities that sustains student interest for the extended time that is necessary to attain conceptual understanding of these core ideas. We also aimed at fostering the development of learners' epistemological awareness regarding the interconnection and distinction between science and technology. Trial implementations of the module were carried out with two upper secondary classes in a school setting, two groups of 15 to 17 year old students who participated in summer science camps and two cohorts of pre-service teachers. From each of these groups, we collected data in the form of three types of student artefacts (constructed magnetic levitation trains, posters and written reports) as well as pre- and post-test measurements of the learning outcomes. After each cycle of implementation, we used the collected data and the feedback from the teachers in an iterative process for the refinement of the module. In this chapter, we present the teaching learning sequence and we discuss the issue of relevance and the role of authenticity in exposing students to epistemic practices.

## **KEYWORDS**

Curriculum design, inquiry-based teaching and learning, technological design, conceptual understanding, epistemological awareness

## INTRODUCTION

There are increasing calls for *inquiry* as the primary context for science teaching and learning (American Association for the Advancement of Science (AAAS), 1993; National Research Council (NRC), 1996). Inquiry is a multifaceted activity (Grandy & Duschl, 2007) and, accordingly, teaching science as inquiry involves students' making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results (Duschl et al., 2007; NRC, 1996). Additional inquiry activities involve the identification of assumptions, the use of critical and logical thinking, and the consideration of alternative explanations. This framework is thought to provide for the development of coherent conceptual understanding, enhanced authenticity to classroom practices and student exposure to scientific methodological processes. In addition, approaching science instruction through inquiry has been shown to promote greater student achievement and improve science learning for diverse learners (Krajcik et al., 1998; Mistler-Jackson & Songer, 2000).

In this context, the issue of holistic science learning is of crucial importance. Holistic learning involves the acquisition of experiences with phenomena, the development of conceptual understanding, the familiarization of students with science methodological processes, the elaboration of reasoning strategies and an awareness of epistemology and the nature of science as well as the facility to engage with the culture and values of science in an integrated manner. Inquiry oriented approaches engage students in science practices with some degree of controlled authenticity. Combining inquiry-oriented science learning with learning through technological design has the potential to promote holistic learning in a context that illustrates the relevance of authentic scientific practice.

It is important that students develop awareness of the role of science and technology in society and to appreciate their distinction and their interrelationships (Constantinou et al., 2010; Hadjilouka, 2009). Science and technology constitute two closely linked areas of human activity, which are strongly interdependent. Despite this strong connection, they are clearly discernible domains of endeavour, in that they serve entirely different social purposes. Science aims at producing reliable knowledge about how systems function; technology seeks to generate solutions to problems encountered by society or to develop procedures or products that meet human needs (AAAS, 1989; Agassi, 1980; Arageorgis & Baltas, 1989; Constantinou et al., 2010; Custer, 1995; Gardner, 1993, 1994; International Technology Education Association (ITEA), 2000; Jones, 2006; NRC, 1996). Design is a core process in technology (ITEA, 2000) investigation is a core process in science (Lewis, 2006). One way of promoting student understanding of the relationship between science and technology is to develop teaching and learning

sequences that are designed to bridge between scientific inquiry and technological design (Lewis, 2006).

Materials Science has played a pivotal role and has emerged as a crucial branch that facilitates that link between science and technology. It is in this branch of science that we now develop standards and instruments for measuring an increasingly diverse set of properties, combinations of which have become increasingly important to the market place. Materials that are strong and light, others that are electrical conductors and good thermal insulators at the same time, have attracted much attention as combinations that are useful for specific applications. In addition, it is also in this branch of science that special materials are designed for customized applications through chemical synthesis and various forms of treatment and testing.

Design-based research approaches have the potential to contribute to the development of teaching and learning sequences that are grounded on established research literature in conjunction with rich data that derive from testing such curriculum materials in authentic classroom environments. According to Bell (2004), design-based research is considered as “a high-level methodological orientation that can be employed within and across various theoretical perspectives and research traditions to bring design and research activities into a tight relation to advance our understanding of learning-related educational phenomena” (p. 245). Consequently, design-based research may impact on eliminating the boundary between design and research (Edelson, 2002), as it gives a great emphasis on the design process as an opportunity to advance the researchers understanding of teaching, learning, and educational systems. It was within the grounds of this research tradition that we undertook the study that we are presenting in the subsequent sections.

## **DESIGN FRAMEWORK**

### **Epistemic Understanding**

Epistemic understanding refers to the core ideas that facilitate our engagement with and our thinking about science (Sandoval & Reiser, 2004). Epistemic understandings facilitate the development of autonomous engagement with self-directed inquiry and the strife for coherent conceptual understanding of specific disciplinary knowledge. Examples of core epistemic understandings are outlined below.

#### *Seeing knowledge as an object of inquiry*

Epistemology is the branch of philosophy concerned with the origins, nature, methods, and limits of human knowledge. Clearly, to develop a personal epistemology about science students must be able to consider knowledge, their own and others, as an object of inquiry, or in other words, an object of cognition (Kuhn,

1993). Students' must be able to explicitly reflect upon what they know, how they know it, and why they claim it to be valid. Furthermore, students need to recognize that scientific knowledge is negotiated and constructed through social interaction, including theoretical ideas, methods for investigating hypotheses, and the criteria by which knowledge claims are evaluated.

#### *Understanding various forms of scientific knowledge*

Scientific knowledge is represented in many different forms that differ in interpretive or predictive power, and that carry certain epistemological commitments. Moreover, various forms of knowledge are used to represent and explain different kinds of things. Theories, for example, offer broad interpretive (and sometimes predictive) power, and generate explanations for particular events. Models are usually explicit representations, often mathematical, of the mechanisms underlying specific phenomena; they are constructed from within individual theoretical perspectives. Scientific models generally attempt to characterize important relations among theoretical entities, their co-functioning and their implications. Laws are empirically grounded relationships between quantities or, more broadly, theoretical entities. Within any given discipline, students need to understand the various forms of knowledge that are valued, and what are the agreed-upon uses for various kinds of knowledge and the methods for generating and evaluating new knowledge.

#### *Understanding criteria for evaluation of knowledge claims*

For students to become active participants in the construction of scientific knowledge, even just for themselves, they need to know the criteria by which scientific knowledge is evaluated. Such criteria include plausible causal mechanisms, simplicity, consistency with observed data, and consistency with existing theories. New theories often are held to a criterion that they contain more explanatory power than existing theories (Kuhn, 1970).

#### *Understanding the reciprocal nature of theory and data*

Expert scientists and philosophers of science recognize that theoretical views influence interpretations of data, and even judgments about what counts as data within a discipline. Conversely, new data can sometimes lead to radical shifts in theoretical perspectives. Theory and data are thus reciprocally related, and it is an over-simplification to think of scientific activity as either theory-driven or data-driven.

### **Epistemic Practices**

Epistemic practices are the cognitive and discursive activities that we would like students to engage in (Sandoval & Reiser, 2004). We identify these activities with the development of epistemic understandings. We suggest that the following practices are core activities for developing epistemological understandings.

### *Explicit articulation and evaluation of group knowledge*

Given that we want students to see knowledge as an object of inquiry and to understand different forms of scientific knowledge, then their science learning should be centered around creating and evaluating knowledge. The argument for knowledge articulation and evaluation is common in current theories of learning. We want to emphasize that this practice is useful for more than deepening students' understanding of science concepts, but is crucial to students' development of sophisticated epistemological conceptions about science.

### *Coordination of theory and evidence*

The central aim of science is to construct theories that interpret natural phenomena. This effort requires the coordination of theoretical ideas with the data that provide evidence of their utility as explanations. A key aspect to the practice of coordinating theory and evidence is the ability to distinguish claims from evidence. The practice of coordinating theory and evidence entails using theories to explain data, and using data to evaluate theories.

### *Make sense of patterns of data*

An important aspect of theory building is the development of interpretive frameworks that make sense of disparate sources of data, by imposing patterns on them. The patterns that scientists identify are constrained by their own theoretical frameworks. For students, the desired practice of making sense of patterns of data includes the explicit consideration of multiple sources of data. Also, exploring the same data from alternative perspectives is an important way to make sense of them.

### *Develop representational fluency*

Representational fluency is the ability to interpret and construct various disciplinary representations, and to be able to translate across representations appropriately. This includes knowing what particular representations are able to illustrate, and to be able to use representations as justifications for other claims. This also includes an ability to link multiple representations in meaningful ways.

### *Hold claims accountable to evidence and criteria*

Understanding the criteria to which scientific claims are held, and the importance of social interaction in the progress of science, requires that students' own knowledge claims be accountable to these criteria. Discourse is a central means to realizing this practice in classrooms. Science classrooms should be organized as knowledge building communities (Scardamalia & Bereiter, 1993) in which discussion and debates about claims and evidence are central activities. Students should be encouraged to justify their claims, and causal claims should be challenged with respect to available data and consistency with other theories and knowledge.

## **MODULE STRUCTURE AND LEARNING OBJECTIVES**

The topic selection emerged from the increasing technological demands for applications of Electromagnetism and the student's difficulty to understand fundamental concepts of Electromagnetism (Chabay, 2005; Raduta, 1997; Tanel, 2008). The module aims to improve students' conceptual understanding of Electromagnetism by concentrating on fundamental principles, decoupling the advanced mathematics and by following a hierarchical and coherent organization of the core ideas. All these facilitate the learning process and allow students to better assimilate new concepts. In addition, the module introduces basic concepts of magnetism and electromagnetism in such a way that knowledge is constructed through students' active participation in hands on experiments and collaborative inquiry-oriented activities.

In brief, the module seeks to (a) help students understand the basic ideas relevant to magnetism and electromagnetism, (b) guide them on a path of emergent autonomy and authentic science practice, and (c) help them understand and appreciate the link between science and technology. These objectives are addressed through engaging students in collaborative scientific inquiry and technological design.

The module employs the technological design approach in the context of an authentic problem-solving scenario which aims to foster students' motivation in applying the acquired knowledge in the construction of a model magnetic levitation train. This technological project provides students a context for experiencing and understanding the closely related fields of science and technology. During the process of design and construction, students are provoked to engage in explicit reflective discourse in which they compare and contrast the different processes, investigation and design, and the different goals between the inquiry and technological part of the module. In this way, students are guided to identify the differences that distinguish science and technology.

The main learning objectives are analyzed in more detail below.

### **Scientific concepts**

Through the module, we aim to help students develop in depth understanding of the magnetic and electromagnetic phenomena and resolve their difficulties and misconceptions by discharging their minds of entrenched ideas that impede their learning progress. The core scientific concepts addressed encompass:

- magnetic interactions (e.g., attraction, attraction and repulsion, no interaction) and the corresponding classes of materials;
- the magnetic field as a model for interpreting interactions at a distance;
- the magnetic domains model for interpreting magnetization and demagnetization phenomena;
- the function of electromagnets, their properties and characteristics.

### **Methodological / Procedural skills / Competencies**

In addition to the conceptual understanding that students are expected to acquire, an attempt is also made to help them develop skills and competencies relevant to the process of technological design, such as the ideas of (a) testing models with respect to their ability to satisfy the specifications and constraints that had been formulated, and (b) refinement of the models so as to optimize their function. Students also engage in measurement and in using their data to draw inferences about the phenomena under study.

### **Reasoning Strategies**

The module involves activities specially designed to help students develop certain reasoning strategies. Specifically, it focuses on the ability to design valid experiments through appropriate control of the relevant variables that may influence the operation of an electromagnet.

### **Epistemological awareness**

Students are systematically engaged in explicit epistemological discourse about the distinction and the interconnections between science and technology. This is intended to help students:

- appreciate the distinction between the different goals of science and technology (producing reliable knowledge about natural phenomena Vs developing solutions to respond to human problems and needs);
- understand the different methodological frameworks that are usually adopted by science and technology (investigation and design, respectively);
- understand aspects of the contribution of science to the development of technology (science provides the knowledge basis for the development/improvement of technological equipment, science formulates questions that necessitate instrumentation i.e., the invention of specialized instruments/processes for measuring, monitoring or controlling);
- understand aspects of the contribution of technology to the development of science (technology facilitates the conduct of experiments by providing instruments and experimental techniques; new technologies tend to initiate scientific research by raising questions concerning the phenomena and mechanisms underlying the operation of these technologies).

### **ACTIVITY SEQUENCE**

The module of Magnetic and Electromagnetic Properties of Materials is a sequence of activities based on guided inquiry, which students follow in order to understand magnetic interactions and their interpretation. This sequence is framed in the context of a project that involves the design and construction of a model for a magnetic train that uses electromagnets for both levitation and propulsion. The rationale is that in this process of technological design students will apply the knowledge they have gained through the inquiry activities in order to construct a