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Technical Brief

A novel e-learning tool for magnetism and magnetic materials

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The purpose of this work is to describe one of the most important phenomena of physics such as magnetism in the form of a website. The title of this website is: http://magworld.physics.auth.gr. In this way, all visitors, even the less experienced, are given the opportunity to navigate easily on this website and gain a broader knowledge of the history of magnetism as well as basic concepts of the magnetism phenomenon and moreover the metrology of magnetic quantities. Depending on their lateral dimensions, magnetic materials are classified into various scales, more specifically macro-, micro- and nano-scales. Through the various categories into which the website is divided, each user can draw information about the properties, effects and applications of the various materials depending on their dimensions. Students are given the opportunity, regardless of their cognitive background, to make a self-assessment through their participation and activation in quizzes of variable difficulty. All information in the site comes from international journals and books and the ultimate goal is to categorize and evaluate information related to magnetism. The information on this site is regularly updated with modern scientific and technological applications. In this way, an electronic reference database is created, which is a practical and useful tool for both teachers and students, as well as researchers who want to obtain information about the wonderful world of magnetism.

Keywords: Online education, Learning environment, Physics education, Context-based learning, Nanoscience

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1. Introduction

Nowadays, various physics phenomena often appear either on websites and/or in databases with various formats. In many cases, however, there is a lack of certain tools that make it easier for teachers, researchers or even students to search for information related to the specific phenomenon and relevant materials and applications (Finkelstein, 2005; Kalkanis & Tobras, 2019). The difficulties arise mainly from the fact that there is usually a lack of evaluation and categorization of information (Hirano & Hirokawa, 2017; Kalogiannakis et al., 2018). Under this framework, the systematic recording of magnetism-related information is the major goal of this study. This can be achieved through the inclusion of historical information, basic knowledge of metrology and a database which attempts to categorize materials in terms of lateral dimensions starting from: macroworld (km=10^3 m) to mm=10^{-3} m) down to, microscale (μm=10^{-6} m)) and nanoscale (nm=10^{-9} nm). Each of these categories consists of four interrelated subcategories relating to materials, properties, phenomena, and applications. In this way, the systematic organization of a significant amount of information and the creation of an electronic database is achieved, which becomes useful for students of all levels, professors and researchers who are interested in magnetic materials. Particular attention is paid to the nanotechnology of magnetism associated with certain materials of fundamental and technological interest,

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highlighting their files and sketching synthetic and formatting aspects as well as some experimental measurements of prototypes (Tsecheri et al., 2019).

Figure 1
The menu bar of Magnetism World website

2. Method

This project aims to attract the interest of all visitors from the less inexperienced to the highly specialized on magnetism and related materials. Visitors may collect information related to magnetic materials, such as the properties and applications of the environment around us, and at the same time obtain a comprehensive picture of the history of magnetism from its inception to the present day. People, in their attempt to explain or clarify their knowledge of the world of Physics, usually create simple mental models. Over time, however, their knowledge in a specific field such as magnetism, expands and so it is advisable to use more advanced models such as a database (Borges & Gilbert, 1998). Obtaining information about the concepts of magnetism lies not only in general knowledge but also in more specialized concepts and phenomena of magnetism. More specifically, the various researchers and students are given the opportunity to obtain useful information about the metrology of magnetic quantities, to proceed with self-assessment of their knowledge through the electronic tools. The information provided to the visitors of the website is also connected with the magnetic materials which have been categorized from the macro scale to the nanoscale as outlined in the menu bar of the website shown in Figure 1 where the bilingual option also is given (English/Greek).

Figure 2
The homepage of the website http://magworld.physics.auth.gr includes the 6 main information areas starting in 1st row with general attributes: It all started like this, You simply need to know-Basic concepts, What and how to measure and continuing in 2nd row with specific categories of materials with respect to their lateral dimensions: Magnetism around us (macroscale), Zoom to microworld (microscale), Down to nanoscale (nanoscale) where respective properties, effects and applications are discussed and specific on-line estimation routines are included accordingly.

For an easier navigation, within the site, each major category is divided into six main information areas, aiming at the smooth transition from one category to another and more specifically to the gradual specialization of all categories. This categorization starts with general information as shown in the first row from left to right: *It all started like this*, *You simply need to know*, *What and how to measure*.

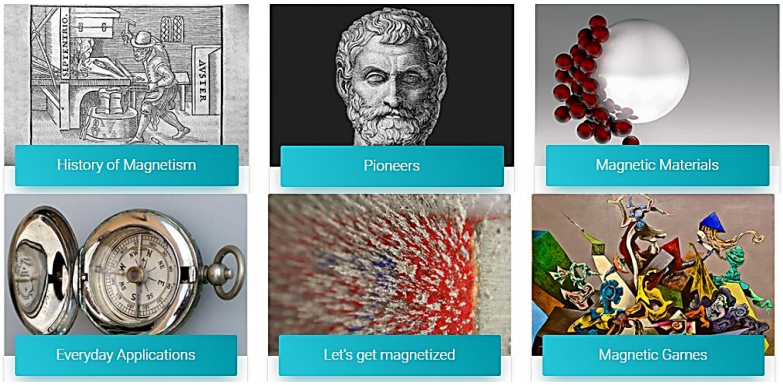
The following three subcategories are associated with magnetic materials in three dimensions from the macrocosm to the nanoscale. In the last three series, an analysis of the concepts of magnetism is attempted as well as the provision of specialized concepts related to materials, properties, applications, and effects with magnetism around us, the micro-scale as well as the nanoscale. This allows users, depending on their background, whether they are students, professors, or researchers, to be able to easily gather information related to various aspects of magnetism as well as related materials.

All information that has been collected and categorized and at the same time constitutes the content of this website has been gathered from publications in reputable international journals and books and in all cases the corresponding bibliographic references are provided. Information is regularly updated to attain updates on modern magnetism-related scientific and technological applications.

3. Results and Discussion

The website consists of six main areas in which the information is presented as it has been categorized and evaluated. In the first row and specifically in the first tab from the left as shown by the corresponding title *It all started like this* the goal is to provide general knowledge that will be easily understood from all visitors whether they are students or researchers (Andrä & Nowak, 2007), as depicted in Figure 3. This card refers to the *history of magnetism* from its discovery to the present day, to those scientists who have left their mark on the course of magnetism, magnetic materials are either referred to as an element or in a more complex form. The data are displayed more accurately with the help of a table to easily access and find useful information related with physical and chemical properties. The historical background is necessary for users to be able to be informed about the problems identified over the centuries regarding the phenomenon of magnetism as well as various scientific questions that were asked as well as the ways in which they were addressed. Children's ideas in conjunction with the historical evolution of concepts such as magnetism and electromagnetism contribute to the consolidation of these concepts and are also a useful tool to understand the world and the phenomena that surround it (Borges & Gilbert, 1998).

Figure 3
The content of the leftmost, 1st general category, named It all started like this, providing the general outline of magnetism, related materials and applications surrounding us



The reference to the pioneering researchers on the phenomenon of magnetism aims to emphasize and highlight their contribution to the evolution of magnetism over the years. For example, Gilbert needs special mention, who through his experiments as well as the books he wrote, played a key role in the development of knowledge about magnetism and electricity (Coey, 2010). In this area, each user can find information about the magnetic characteristics of various materials that are part of the macroscopic scale as well as the applications that surround us in our daily lives. Finally in this area there are two cards which can be characterized mostly as educational cards. The first of these is entitled *Let's get magnetized* and can be considered as a journey based on educational fun and dealing with various aspects of magnetism, such as children's activities, high school experiments and modern applications of magnetism in nanotechnology. The next one, entitled *Magnetic Games*, includes a series of links where one may find everything from magnetic-based online toys to magnetic educational materials and magnetic kits.

The second tab entitled *You simply need to know* refers to the general background of knowledge related to magnetism and consists of six subcategories (Figure 4). More specifically, the titles of these subcategories are the elements, the basic knowledge, the magnetic phenomena and the distinctions in the three scales as described in detail the macro-scale, the micro-scale and the nanoscale. Regarding the periodic table elements, their presentation is in tabular form where the basic characteristics of a periodic table are listed as well as the main physical and chemical properties of these elements.

Figure 4
The category named You simply need to know, consists of knowledge framework concerning magnetic elements, basics of magnetism, fact & figures and representative characteristics at the three scale regimes: macroscale, microscale, nanoscale

The next category related to *Basics* refers to the basic knowledge about magnetism, including basic definitions and phenomena, to help deepen understanding in the relevant field of magnetism. *Facts & Figures* collects information on magnetic performance with respect to magnetic fields and magnetic materials. For example, how big is the Earth's magnetic field or how strong is the magnetic field of a household magnet. The last three tabs refer to properties and phenomena related to magnetism, the corresponding materials and applications on the *Macroscale*, *Microscale* and *Nanoscale*.

The title of the next tab is *What and how to measure* allows visitor to search for useful and practical information in more specialized concepts such as *Quantities and Units* as well as the *metrology* of magnetic quantities (Figure 5). More precisely this subcategory of *Quantities & Units* tab, for example, describes the intensity of a magnetic field, if there are other relevant physical quantities, and what units are used. In the next subcategory entitled *Metrology* are mentioned concepts and information about the reliability of magnetic measurements and experiments as well as the safe calculation of relative quantities.

Figure 5
The rightmost tab of 1st row named What and how to measure, provides relevant information on quantities & units, magnetic metrology, devices, types of measurements (static/dynamic) and basic on-line calculation datasheets of basic magnetic quantities.

Devices refers to measuring devices used to characterize magnetic materials and at the same time indicate the operating principles, advantages, and disadvantages. *Static measurements* collect information about static (DC) magnetometry techniques for characterization of materials and at the same time to examples of protocols and related experimental data sets. Following is *Dynamic Measurements* which outlines dynamic (AC) magnetometry techniques for characterization of materials. Thus, the user may get acquainted with the role of a specific measuring sequence and observe, for example, illustrative datasets outlining the performance of typical magnetic materials (Balasubramanian et al., 2020; Nouailhat, 2008).

The *Calculations* tab is the last in this category, which includes quantitative tools for on-line estimations of magnetic quantities typically met in magnetic experiments or simulations. A typical example of an on-line calculation sheet is given in Figure 6. In the following, a series of tabs leads to different calculation sequences. Based on the classification of materials in three scales according to their dimensions such as

macro-scale, micro-scale and nanoscale, a more detailed description of the magnetic materials in each of these three scales is attempted, as shown in Figure 7.

Figure 6

The What & How to measure – Calculations tab contains a series of on-line google sheets (names at bottom row) where user may estimate readily magnetic quantities. Constants and magnetic quantity reference values are collected from textbooks, review articles and commercial websites.

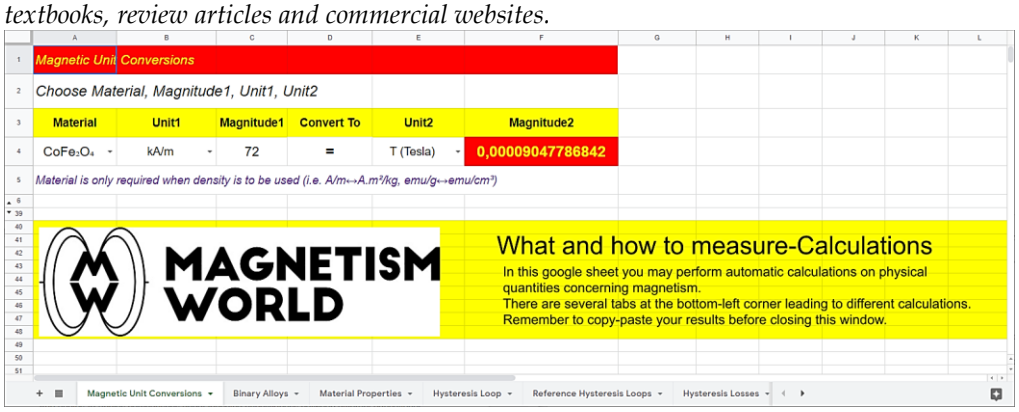
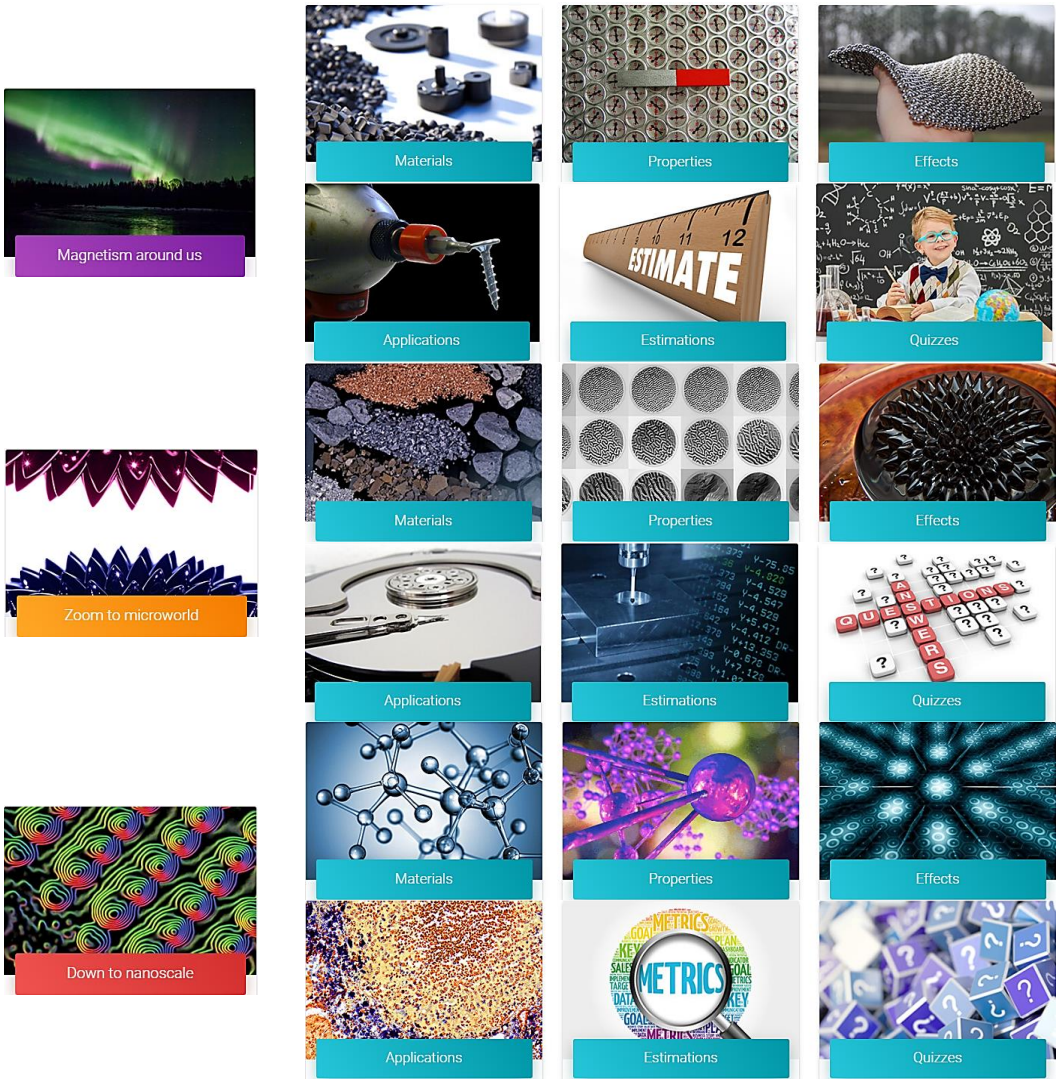


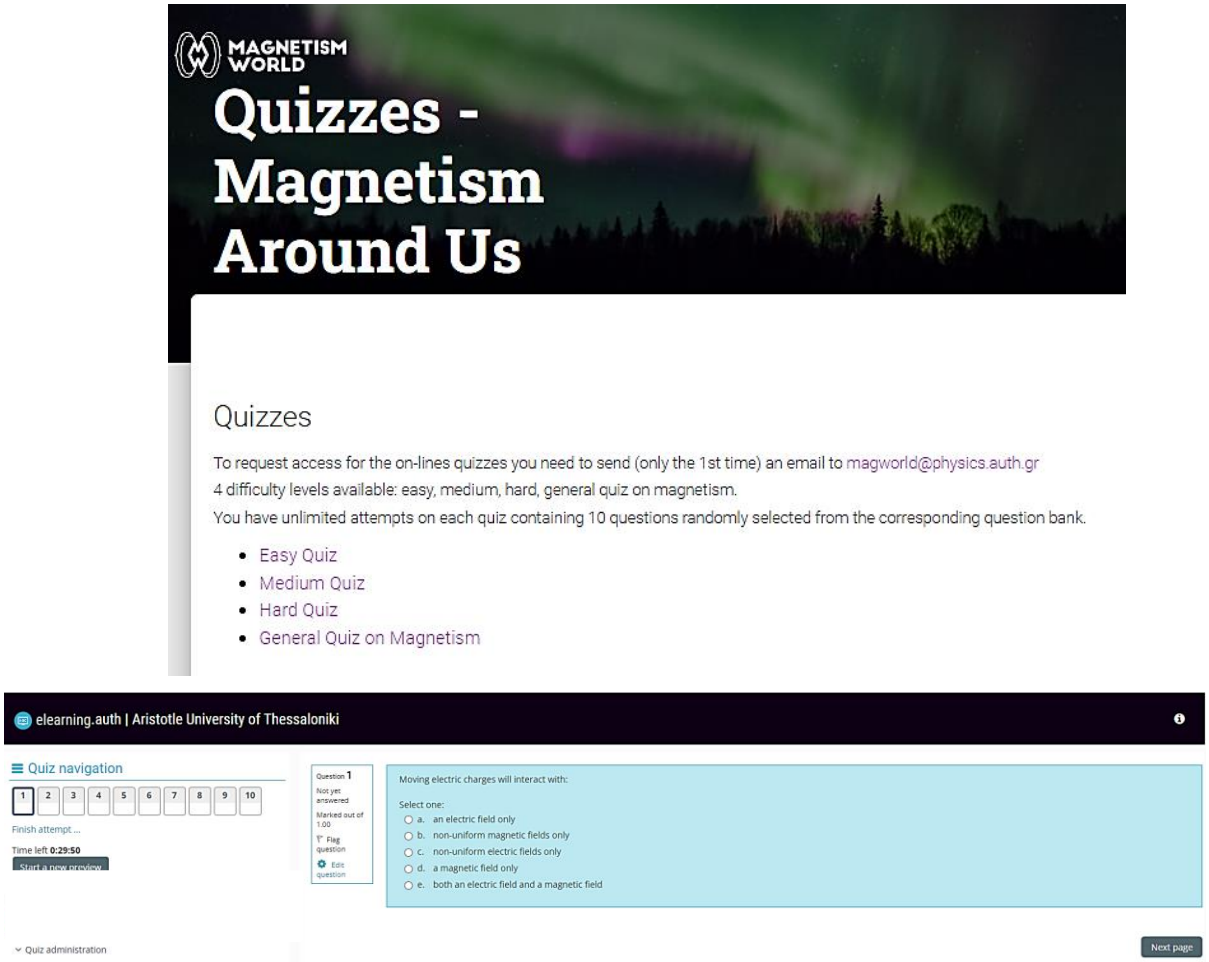
Figure 7

Magnetic Material classification with respect to their lateral dimensions: Magnetism around us refers to dimensions from universe down to the mm range. Zoom to microworld collects magnetism relevant information at the micrometer range (10^{-6} m). Down to nanoscale focuses on modern aspects of nanomagnetism (10^{-9} m)



More specifically, regarding the first four subcategories in each case, information is collected about the *Materials*, the *Properties*, the *Effects,* and the *Applications* of the magnetic materials at the specific scale. In each materials' category the last two tabs include on-line sheets focusing on corresponding magnetic quantities. as well as quizzes of graded difficulty again under the framework of the scale regime they belong to. Each *Estimation* tab is a handy on-line calculator to estimate quantities commonly found in magnetic studies and are considered necessary for the evaluation and interpretation of data by students, young researchers and scientists. Schematically, these online tools provide corresponding size estimations analogous to the *What & how to measure-Calculations* tab depicted in Figure 6 yet focusing on the specific scale regime (macro, micro, nano). Typical pieces of information in the category *Magnetism around us* include the hysteresis loop, the energy product and the anisotropy constant.

Figure 8
On-line quizzes with 10 random questions of graded difficulty (Easy, Medium, Hard, General) automatically generated from a question data bank of more than 300 questions.



The last tab in each of the materials' categories is *Quizzes* which includes multiple-choice quizzes of 10 random questions with graded difficulty. To be precise, a question bank has been created with more than 300 questions categorized into easy, medium and difficult. Quizzes are handled by a university eLearning facility and statistics and evaluation scores are automatically generated. Student may repeat the randomly generated quizzes many times.

At this point it should be noted that special attention is paid to microscale magnetic materials in terms of collecting and evaluating up-to-date information about them. For example, in the *Zoom to the microworld* tab we focus on the properties of materials and the metrology of magnetic materials with one or more dimensions in the microscale area. More specifically, the micrometric evaluation of the magnetic characteristics that appear in these dimensions is attempted and at the same time procedures are proposed to draw correct conclusions of collective magnetic characteristics both qualitatively and quantitatively. Thus, it is found, for example, that the more unstable the magnetization of a material, resulting in some

constraints, the smaller the size of that material. What are the limitations of magnetic recording media? How does temperature affect an unstable magnetic moment?

As we move to materials located in the nanoscale where one or more dimensions are limited to the nm region and therefore approach the atomic plane, the magnetic properties are affected. The phenomena that occur in the specific area and in the specific dimensions can be considered different and innovative and for this reason a better theoretical background is often required (Czichos et al., 2006). At the same time, terms such as magnetic anisotropy and superparamagnetism can provide information about magnetism based on atomic theory. An interesting category of materials for both scientific and technological exploration are magnetic nanostructures with one, two and three nanodimensions. This is due to advances in both magnetism and magnetic materials (Martin et al., 2003; Vajtai, 2013).

The aim of this study is to highlight, on the one hand, the connection between the properties of materials and applications in each category and on the other hand, the role played by the categorization of materials according to their dimensions. For example, how is the magnetic deflection of a material affected by specific parameters such as dimensions or temperature affected? At the same time, all visitors are given the opportunity to be informed about how some properties can be changed or modified as well as applications of magnetic materials such as energy product and magnetic anisotropy.

The most important points of this work are the systematic recording of the evolution of magnetic materials and their properties, their characteristics in depth in the field of nanotechnology and the use of experimental data for technological applications as well as the processing of experimental data in low-dimensional materials.

This website highlights the following educational goals for the phenomenon of magnetism:

- Unified framework on the phenomenon of magnetism. In terms of providing information, a logical flow is sought in order to facilitate each user in the search for data related to the phenomenon of magnetism.
- Clarification and deeper understanding of the concepts related to magnetism for someone who has a basic background on the concepts of physics and in particular the concepts of magnetism (Calderón & Ruíz, 2019). At the same time, the presentation of properties of materials as well as their applications in a simple and accessible way is our aim (Borghes & Gilbert, 1998).
- Facile search for material properties and applications associated with the phenomenon of magnetism. The aim is to collect valid information and classify them. In this way, a critical mass of people is given access to valid information about phenomena and modern devices related to magnetic properties (Bozzo et al., 2019).
- A wider range of material dimensions is described in order to connect the magnetism phenomenon as well as the properties of magnetic materials with the real world. The classification is done in such a way that the observation starts from the outside and completed inside. As we typically mention, it starts from the universe and reaches inside the human body.

A database that contains up-to-date information is the final product and thus allows potential users to easily search for materials, properties and applications. In order to achieve evaluation both nationally and internationally, the website is bilingual (English/Greek). The evaluation of the website is attempted with test invitations or visits of different age groups coming from the Elementary School, the High School and the University of both students and teachers (Mueanploy, 2016). The website includes online magnetic feature calculations and online grading tests randomly selected by a query bank as well as, regularly updated. The closed-ended questions included in this questionnaire enable the user to delve into concepts in an interactive way but at the same time achieve instant feedback via online answers (Gunawan et al., 2021; Jing & Chandralekha, 2016). The functionality of the site is significantly improved through the interaction whether we refer to the technical part or its content (Gunawan et al., 2021; Jing & Chandralekha, 2016). This allows all users depending on their cognitive background to collect information about magnetism (Gunawan et al., 2021; Pryotz, 2020). Study results show that science teachers can achieve spectacular results by guiding their students to work systematically to develop their own theories and ideas (Hakkarainen, 2004). It seems that understanding different concepts, especially on the part of students, can benefit from systematic teaching and organization especially when dealing with complex topics such as Physics.

4. Conclusions

This work is an interactive tool for exploring magnetism in all dimensions in an original way. Every potential user is given the opportunity to obtain information about all manifestations and forms of magnetism as well as in all dimensions from macro to nanoscale. The website was designed in such a way as

to aim and target the interaction of the users, something that is achieved through specific activities. Activities such as online quizzes with grading difficulty, on-line calculators that are designed to be accessible, innovative tools such as interactive games are a special way of approaching and exploring the magnetism world. Through these activities, inexperienced visitors, such as students, are given the opportunity to understand the concepts related to the phenomenon of magnetism and on the other hand, more experienced visitors i.e. researchers are able to deepen their pre-existing knowledge about the concepts of magnetism. The knowledge gained in this way can be considered highly effective, interesting, fun and modern. At the same time, it follows the requirements of the twenty-first century and adapts to the conditions of modern technology. Ultimately, the reference database provided by this site can be considered practical and useful for anyone interested in entering and exploring the wonderful world of magnetism.

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Ethics declaration: This study focuses on the development of a web-interface for the study of magnetism and magnetic materials using secondary data provided from the literature. No human subjects, human participation or personal data were incorporated at any stage of this implementation. Therefore, ethics approval is not required.

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