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PHYSICS EDUCATION

INQUIRY-BASED SCIENCE EDUCATION IN DIMENSIONAL MEASUREMENT TEACHING

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Abstract. This paper describes a set of learning units devoted to dimensional measurement teaching, units developed in the frame of the research project “Inquiry-Based Education in Science and Technology – i-BEST”. The principles of such measurements are introduced according to the international practice in the field, the proposed activities being designed following the major ideas of inquiry-based science education (IBSE), as they emerged from recent European projects. The learning units follow the national curriculum and they where developed to target a broader audience, from kindergarten to lower secondary school. According to our approach, concepts are introduced to children gradually, correlated to their age and cognitive development.

Key words: distance, inquiry-based teaching, learning units, length, science education.

1. INTRODUCTION

This paper describes a set of learning units devoted to dimensional measurement teaching, units developed in the frame of the research project “Inquiry-Based Education in Science and Technology: i-BEST”. The principles of such measurements are introduced according to the international practice in the field, the proposed activities being designed following the major ideas of inquiry-based science education (IBSE), as they emerged from recent European projects. The learning units follow the national curriculum and they where developed to target a broader audience, from kindergarten to lower secondary school. According to our approach, concepts are introduced to children gradually, correlated to their age and cognitive development. The study begins with a short overview of the European context which led, in the last eight years or so, to the proliferation of EU funded research projects devoted to IBSE. The next section addresses the major issues related to inquiry science education as it was debated by experts in the field. Such a demarche will assist us to explain our methodology adopted in preparing the learning units. The third section places our research activity in the national frame of science teaching and justify the way we embedded IBSE principles into our work. The final section is entirely dedicated to the presentation of the learning units' philosophy, and the way they are structured, introducing in a compact manner the practical activities proposed to be run in science class. Our approach is supported by a short overview of pedagogical concepts related to dimensional measurements, as described in the science education literature. The module which gathers these learning units is quite extended, the diversity of the activities recommending them to be used during the science class, or as extra curricular or after school lessons.

2. THE EUROPEAN SCENE

The concerns of EU's decision makers on the evolution of the labor market in the next decades, especially in scientific research, technological development and innovation, generated a set of programmatic documents highlighting: the urgent need to train a large contingent of specialists in science and technology [1]; the shortage in Europe of a workforce ready to be involved in highly skilled techniques (in Europe there are 5.7 researchers per 1,000, as compared to 8.08 in U.S. and 9.14 in Japan) [2]; that math and science should begin to be taught at early age (pre-school) and they must be connected to student's real life experience [3]; the need for new educational policies and mechanisms to ensure innovative forms of teaching and learning of science, which correspond to a proper learning environment by involving students in practical activities, experimental (hands-on) work, associated with appropriate teachers training [4, 5]; the requirement that teachers, at any level, have to be trained in accordance with the scientific inquiry method (Inquiry-Based Science Education – IBSE) [6]; that teachers must have both content knowledge in the taught field and understanding of the way science works [7]; that the process of training in school and out of school must be used to develop and strengthen new skills and competencies [8]. In a broader context, an OECD report states imperatively that science learning has to be close to the day-to-day life experience, through a multidisciplinary approach [9]. The process of designing science learning units has to consider the recent findings of two studies, radiographs of the European educational system in teaching science and mathematics, studies emphasizing the gaps existing between the Romanian educational system and those of advanced European countries with an extensive experience in using IBSE [10, 11]. Attempts to support science education took different forms, such as: computer-based learning [12, 13], multimedia-oriented learning strategies [14] or learning physics by experimental reasoning [15].

3. SEVERAL PERSPECTIVES ON IBSE

In our approach we considered several principles of teaching and learning science and mathematics according to scientific inquiry (Inquiry-Based Science Education – IBSE, Inquiry-Based Science Learning – IBSL or Inquiry-Based Science Teaching – IBST), as they are defined by the current studies.

In 2004, Linn, Davis and Bell described “inquiry instruction” as engaging students in the intentional process of diagnosing problems, critical evaluation of the experiment, distinguishing alternatives, planning investigations, researching conjectures, searching for information, debating with peers, seeking information from experts, and forming coherent arguments [16].

Wynne Harlen, a recognized expert in the theory and practice of IBSE, wrote in 2011 “IBSE means students progressively developing key scientific ideas through learning how to investigate and build their knowledge and understanding of the world around. They use skills employed by scientists such as raising questions, collecting data, reasoning and reviewing evidence in the light of what is already known, drawing conclusions and discussing results. This learning process is all supported by an inquiry-based pedagogy, where pedagogy is taken to mean not only the act of teaching but also its underpinning justifications” [17].

A very recent report of The European Federation of National Academies of Sciences and Humanities defines IBSE as being an “approach that reproduces in the classroom the learning process practiced by scientists: observing, formulating questions, doing experiments, collecting and comparing data, reaching conclusions, and extrapolating these findings to more general theories”. Switching to such an educational model requires additional theoretical investigations, a more profound assessment of results, combined with appropriate methods devoted to teachers’ initial education and continuous professional development [18].

To the legitimate question “What offers IBSE to the learner?” the straight answer is: IBSE provides the opportunities to [19]: “manipulate objects and materials and observe events; use evidence from a range of other sources of information including books, the Internet, teachers or scientists; raise questions for investigation, make predictions, plan and conduct investigations, solve problems, test ideas, reflect on new evidence and develop new hypotheses; collaborate with others, share their ideas, plans and conclusions; advance their own understanding through dialogue with others”.

We conclude the short review on ideas reflecting IBSE meaning by citing the definitions given by two authorities in the United States. According to the National Research Council (NRC) “inquiry is a multifaceted activity that involves: making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations" [20]. The vision on the subject of the National Science Foundation states "inquiry teaching leads students to build their understanding of fundamental scientific ideas through direct experience with materials, by consulting books, other resources, and experts, and through argument and debate among themselves. All this takes place under the leadership of the classroom teacher" [21].

The experienced reader, a practitioner teacher, will certainly notice the way the listed IBSE principles fit to terms defined by Bloom's taxonomy, and its subsequent developments, on the cognitive process [22]. Competences/skills/ capabilities, as defined by Bloom, can be found in IBSE practice: a) knowledge (recall information) occurs in IBSE by defining at the beginning of the investigation, any previous student's ideas and opinions; b) comprehension (understanding a meaning, paraphrasing a concept) it is the IBSE principle, its goal being to assimilate concepts through direct, personal experience; c) application (using information or concepts in new situations) it is essential to IBSE method, as students learn to use in new situations prior knowledge, by manipulating concepts learned; d) analysis (breaking concepts and information into component parts for a better understanding) is present in IBSE practice when the student is required to observe, compare, classify, sort, rank objects, events or phenomena; e) synthesis (putting ideas together in order to produce something new) occurs in IBSE learning when the student, being placed into a new situation, has to "assemble" knowledge acquired through various means, from various sources, to solve a problem or to build a model; f) evaluation (making judgments about value) is one of the fundaments of the IBSE method, as the students are asked to formulate conclusions and arguments, to present the results, to take part to debates and confrontations when different views / solutions are expressed.

We have mentioned also the impact on the design of the learning units recent we developed, of the studies undertaken in the frame of the European project "Creative Little Scientists", which is trying to establish a correlation between the methods of teaching science and mathematics, and the development of creativity in early education [23, 24].

4. THE CONTEXT OF THE PROJECT

The set of learning units accompanying the training kits representing the outcome of studies conducted under project "Inquiry-Based Science and Technology Education – I-BEST" was designed considering the results of recent research in science teaching and learning, pedagogy and cognitive science. The principles considered for these units have been adapted to the specific context of today science teaching requirements, the needs of teacher education, the current curriculum. Whenever possible, these principles have been applied by way of example, in order to familiarize Romanian teachers and students with European practice, as they emerges from EU projects implemented in the last eight years, projects that brought important theoretical and practical contributions (courses, lesson plans, case studies, demonstration sessions). The authors were able to attend, and in some cases contribute directly to some of these projects, for example, Pollen (http://www.pollen-europa.net/?page=CLDGDJVwskY%3D) Fibonacci (http://www.Fibonacci-project.eu/), "Discover" (http://education.inflpr.ro/ro/ Descopera.htm) and Creative Little Scientists (http://www.creative-little-scientists.eu/ home).

The learning units developed within the "Inquiry-Based Education in Science and Technology – I-BEST" project (http://education.inflpr.ro/ro/IBEST.htm) represent a response to repeated requests made by Romanian school teachers with whom the authors interacted during the development of several national and European educational projects. A major deficiency of the Romanian science teaching is represented by its too theoretical character, practical learning of concepts occupying a minor space in the economics of science classes. In addition, teachers complained about the almost total lack of minimum facilities allowing them to run hands-on activities in the classroom. Another major deficiency is represented by partial mastery of basic science subject knowledge by teachers in preschool and primary education, whose initial training or professional development does not explicitly include knowledge of natural sciences and technology. These limitations put them in difficulty to teach science efficiently, in the context of the new adopted legislation and under the new science curricula, the focus now being on the development of skills, inter-disciplinarily, demand for forming attitudes, understanding and manipulation of concepts, study in a personalized context in which student learning is the focus. This new approach accurately reflect the modern science teaching methodology, by using the scientific investigation (inquiry-based science education – IBSE), method studied and developed in many European projects funded in the last years [25]. Participation of the Centre for Science Education and Training – CSET at the National Institute for Laser, Plasma and Radiation Physics (http://education.inflpr.ro/ro/home.htm) to several European projects, as well as the expertise obtained through our international partnerships established over the past eight years allow us to support the change of science teaching, by developing learning units designed to meet teachers needs and expectations.

In this demarche, we started from several principles defining IBSE [26–30]: the knowledge and understanding of the world surrounding the student is done effectively only through direct experience; new skills, abilities, habits, critical thinking, creativity and entrepreneurial spirit are acquired if the student investigates and discovers the reality alone or assisted by the teacher; it is important to develop students abilities which provide help in solving real life problems, in situations new for them; of course, acquiring general knowledge will count, but more important is the understanding and the manipulation of basic concepts and the ability to transfer knowledge gained in one area to other fields, keeping the specificity of each subject; for now, it is essential for the student to learn the skills related to lifelong learning, to acquire the ability to search and exploit information in an appropriate manner, and to adapt the available learning strategies to concrete means and tasks; it is essential that students are trained to ask questions, to clarify a situation, to formulate hypotheses, to design adequately experiments, to interpret results and to present conclusions, supported by evidence-based arguments; theoretical knowledge and practical experience make sense to the student when connection to real life situations is revealed, when the student understand the way science and mathematics help us to solve new problems.

The training kits accompanying the learning units were designed to demonstrate concepts, to conduct simple experiments, to build simple tools, by using inexpensive, accessible materials. In this way, teachers can be persuaded that quite laborious investigations can be run using inexpensive materials which in most cases, students can find in the household.

We included in project context the term “technology” because we expect that by using these kits the students will develop not only their analysis and synthesis capacity, and logical and critical thinking, but also hands-on skills helping them to implement into practice what they learned, illustrating at small-scale the impact science has on our everyday life and on the development of our civilization. An important component of the pedagogical approach we propose represents the change of students’ attitudes towards nature and society, the increase of their confidence and self-esteem by developing their abilities to relate to the society. By completing the activities proposed in the learning units, students will understand the concepts, will practice the design of experimental procedures, will understand the essence of the measurement process as it refers to lengths and distances, will familiarize them with the rigor and logic of the scientific approach, will teach them the use of adequate language description of the situation, phenomena and events.

We started the series of learning units with a set dedicated to measurements, as the study of natural sciences involve, in a way or another, some sort of measurement; it is not possible to conduct a scientific investigation without following the methodology of measurements and without understanding the philosophy of this science.

5. THE LEARNING UNITS

5.1. PRINCIPLES OF DIMENSIONAL MEASUREMENTS

In line with modern educational practice adopted in teaching the concepts of lengths and distances measurement, we included, in the kits and in the learning units that accompanies them, activities to support students' understanding of fundamental concepts in the field [31–35]:

- *identifying a quality of an object as being its length* (as an extension to width or height): Objects can be classified benchmarking their qualities (size, weight, color, smell, texture, etc.). The aim of the learning unit is to assist the student in identifying the quality associated to the length of an object (more general its dimensions) and to clarify the difference between the length (the size of an object along one direction) and distance (the interval between two points in space which can be located on the same object or not). For example, consider the case of a table on which are placed two pieces of chalk, at a certain distance one from another. The size of the table (*e.g*. its length) represents its expansion along one direction in space, while the remoteness of the two pieces of chalk which can be regarded as marks the positions of two points on the surface of the table, is defined as the distance. So the size (for simplicity length) is a feature associated to an object, while the distance reflects the relative positions of two points in space, belonging or not to the same object. The measurements of lengths and distances are based on the same procedures, use the same kind of tools and units of the same category (*e.g*. the meter and its (sub)multiples).
- *conservation of an object length*: Normally, if no external pressure, expansion or contraction phenomena, changing of the state, etc. are applied, the length of an object is preserved regardless of its position or orientation in space. The size of a book is the same regardless whether the book is placed on a table or lies on a library shelf. This concept enables reproduction of measurements using a unit which keeps its size, being it a standardized or customary unit. In addition, based on this property, objects ordered following a benchmarking criterion do not change their position in an established hierarchy.
- *transitivity of the measurement process*: Comparison of two objects can be done either directly by overlapping or indirectly by comparing each object with a third object. This is the very essence of the measurement process when ordering two or more objects is done by comparing them with the same unit of measurement ("the third object"). This feature allows the investigator to evaluate the length of two objects that might be not in the same location or can easily joint.
- *additivity*: As a result of conservation of length, the length of a segment composed by two or more segments connected to one another, but no overlapping, is equal to the sum of the individual lengths of the segments that compose it, regardless of the order the constituent segments are joint.
- *using the same unit of measure throughout the entire measurement process*: The accuracy and reproducibility of measurements is granted by the use of the same unit of measurement, standard or non-standard, over entire set of measurements.
- *repeated use (iteration) of the measurement unit*: By measuring a length or distance implies a repeated positioning of the selected, and same, measuring unit along measured interval. In other words, length measurement requires the repeated operation of measurand division by the chosen unit, along with the

counting of the division steps. In this repeated process overlapping or superposing the measuring unit in adjacent steps has to be avoided.

- *localization of the "zero" position*: Any part of the measuring instrument (ruler, measuring tape, etc.) can be considered the origin of the measurement, the "zero point". In all situations, the measurement result has to be expressed as the difference between the final indication of the and arbitrarily selected "zero point".
- *proportionality of the measurement results*: The ratio of the number of steps of the iteration varies inversely with the ratio of the units employed. If the same length (interval between two points in space) has to be measured with two different units, few steps are required for the longer unit used than for the shorter unit. This feature has to be considered when the unit to be used is selected, in order to achieve compatibility between the unit and the measurand; the measurement has to be done in a reasonable number of steps, with the required resolution.
- *expression of measurements results*: The result of a length or distance measurement can be represented by different numbers according to the unit considered. In practice, this feature has to be correlated with the measurement data processing, by expressing the results in various units, and using multiples or submultiples of the basic unit, as appropriate.

We bring here into discussion these principles, because, in spite of the fact that they are accepted by the scientific community and educational experts, they are not at all obvious to Romanian school teachers, who are mostly concerned with units conversion and the use of some simple measuring tools and are not aware of the importance of the concepts which have to be taught. Teachers who will use the measuring kit have to study very carefully these concepts and to work in the classroom in such a way that these concepts are well understood by students, being imperative to develop to their students specific skills, which form the fundament of all measurements in scientific investigations.

5.2. DESCRIPTION OF THE LEARNING UNITS

The educational module on length/ distance measurements includes seven learning units. The proposed learning units were designed to illustrate in a gradual manner the above mentions principles of length/ distance measurement, by integrating in the mean time the ideas associated to IBSE. We included more traditional activities, in order not to confuse school teachers accustomed with a specific practice, as well as some very innovative, original methods, based on up-to-date technologies. Some of the activities use very simple materials, which can be found in every household, while more sophisticated activities were developed around sensors and data loggers, designed by the project team. The learning units cover the following subjects, with the learning objectives mentioned below:

• the learning unit 1 – measurable characteristics, length measurement, comparing objects' length, with a focus on: the development of skills to observe, compare, sort, classify; the evaluation of objects' measurable characteristics; the measurement of objects by comparing their lengths;

• the learning unit 2 – non-standard (customary) measuring units, with a focus on: the use of non-standardized measurement units for the estimation of objects length;

• the learning unit 3 – standard measuring units, with a focus on: the need for standardized measurement units; their use; multiples and submultiples of the basic unit;

• the learning unit 4 – description of tools used to measure lengths, with a focus on: the need for the use measuring instruments; practice with simple measuring instruments for length measurement;

• the learning unit 5 – distance, distance measurement, with a focus on: introducing the concept of distance; experiments for distance measurement;

• the learning unit 6 – construction of instruments for length and distance measurement, with a focus on: the development by students of tools for measuring lengths and distances; calibration of these instruments;

• the learning unit 7 – hands-on examples of length measurement, with a focus on: applications of length measurement to prepare the layout of objects in the classroom; drawing of a set-up to furnish a room; evaluation of details in a picture; using of proportions; study of the human body parts; study of shadows; outdoor activities in the school yard.

Each learning unit includes several practical activities; overall there are 30 such activities. The structure of every learning unit can be described as follows: the title and the field of study (*e.g.* science, environment, mathematics); the grades and the references to school curriculum (reference objectives) for every grade the unit can be applied to (*e.g.* "sorting and classifying objects according to their characteristics", pre-school curriculum item 5.1 and first grade curriculum item 2.2); specific competences developed; expected results by the end of unit activities; list of materials required to fulfill the tasks and included into the training kit; additional readings (if it is the case); annexes, such as student's worksheets, templates of evaluation file, etc. For each activity, the teacher is assisted by the procedure to use materials and teach the subject; the major messages of the activity ("take-home" ideas); some model questions to be addressed to students in order to assist them in planning, running and evaluating the activity. As mentioned previously, some activities require special devices or instruments (sensors, data loggers). We included such activities in the module to familiarize pupils with modern technologies and data processing. In one example, students have to assemble a distance measuring wheel, to calibrate it and to do some outdoor measurements. Another very interesting instrument we devise is an innovative ultrasound-based equipment to be used in conjunction with a laptop and a dedicated software to measure distances, velocity, acceleration, liquid or powder level in a container, etc. [36]. The unit includes also some template forms, both for students' formative assessment and student self-evaluation.

5.3. EXPECTED OUTCOMES

Four types of outcomes are expected to be reached by pupils after the module on length and distance measurements is entirely concluded:

A. advance in scientific knowledge: identification of objects measurable characteristics; definition of length and distance; use of length measuring instruments; units of measure; comparison with a measuring unit as a way to estimate lengths and distances; non-standard and standard units of measure;

B. improvement of competences: ability to observe; skills to compare, sort, order objects according to certain criteria; logical approach to problem solving; ability to follow a procedure; skills to locate and classify information; activities planning; formulating questions; designing an experiment; use of instruments; multidisciplinary approach; capacity of analysis and synthesis; interpretation of results; reflection on his/ her own activities; draw conclusions; ability to argue and communicate; ability to develop models and to apply the acquired knowledge in new situations; use of scientific language.

C. education for new attitudes: increased of self-confidence; compliance to normative conduct during activities; taking calculated risks in running experiments; tolerance for colleagues opinions; willingness to cooperate; development of critical thinking; critical self-evaluation; development of creativity.

D. developing practical and technical skills: construction of instruments for measuring length; drawing of set-up plans of closed or open spaces; use of drawings and graphs; construction of an instrument to measure distances; use of ICT in gathering and processing data.

6. CONCLUSIONS AND FUTURE WORK

The paper summarizes our endeavor to develop a model educational module to teach dimensional measurements to pupils from pre-school to the 7-th grade, based on the principles of inquiry-based science education. The innovative contribution to measuring teaching is provided by the structure and contents of the learning units, the hands-on/ mind-on approach and by the use of both trivial materials and more sophisticated instruments. This approach respond to today pedagogical requirements and follow the guide line of several successful European projects as it concerns the use of IBSE. Next steps in our work will follow similar pedagogical patterns, introducing students to the worlds of sounds, light, colors, materials, etc.

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