ORIGINAL PAPER

INTRODUCING RESPONSIBLE RESEARCH AND INNOVATION DIMENSIONS IN NON-FORMAL EDUCATION ACTIVITIES DEDICATED TO INDUSTRIAL APPLICATION OF NANOMATERIALS

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Abstract. *It is clearly anticipated that Nanotechnology plays an important role in the technological development of the actual period, introducing higher performance materials, intelligent systems and new methods of production, with significant impact for all the societal aspects. What is happening in the present can be considered as the beginning of a revolution based on the human ability to work on the same scale as nature. In this respect, secondary education has to consider the area of Nanoscience / Nanotechnology as a special chapter in the process of educating the young generation, taking into account that it involves a multidisciplinary natural Science education, providing concepts met also in Physics, Chemistry, Biology and Mathematics.*

This paper underlines some aspects of the non-formal activities carried out by the young students to know general concepts about nanomaterials and their industrial applications, together with the introduction of Responsible Research and Innovation dimensions. The activities were organized using the discovery-based learning method, so that students participated actively in debates, bringing arguments on their claims. The groups of students were also involved in investigating or solving community problems, introducing several solutions based on the exploitation of some typical nano-products. The problems were tried to be solved through group discussion, with proposals for alternative solutions, by motivating the choice of the final solution. All the illustrated activities were part of a special Unit dedicated to Industrial Applications of Nanomaterials, designed in the frame of the EU FP7 project entitled: "IRRESISTIBLE - Including Responsible Research and Innovation in Cutting Edge Science and Inquiry-based Science Education to Improve Teacher's Ability of Bridging Learning Environments". At the same time, the carried out activities contributed to the formation of conscious and responsible attitudes toward the importance of using certain properties of nanomaterials in various industrial applications.

Keywords: *non-formal education, Nanotechnology, nanomaterials, discovery-based learning, IRRESISTIBLE project.*

1. INTRODUCTION

Nanotechnology encompasses a variety of subjects such as Chemistry, Physics, Engineering, Materials Science, Biology, and Medicine. This ever-evolving area is rapidly growing in industry and research, and the need for teaching strategies for the integration of

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Nanotechnology (also into the curriculum) has been recognized in the Engineering Education and Science Education due to its multidisciplinary nature [1]. It is clear that Nanotechnology becomes a main actor in the technological development of the actual period, through the introduction of intelligent materials, by proposing systems and new methods of production, with promising series of industrial applications of nanomaterials. They include a range of consumer products such as ultraviolet filters in the sunscreen cream and devices that prevent the formation of odors. However, there are also many medical and technical applications, like the antitumor therapies or lithium-ion batteries which can deliver electric energy to the cars or solar panels. Those applications have the potential to generate significant technological advancements and, therefore, the use of nanomaterials was identified as a generic essential component of new technologies.

The benefits of nanomaterials range from applications related to saving human lives (medical applications) to those that generate simple innovations and improvements in consumer products. Also, the risks and exposure of the workers or consumers differ greatly from total absence till potential important risks that need to be addressed. On the basis of the current knowledge, the nanomaterials are similar to common products / chemicals, meaning that some may be toxic, while others not. Possible risks are linked to the specific use of nanomaterials. Therefore, nanomaterials require a risk assessment that must be carried out in a *case-by-case* basis, using relevant information. The current risk assessment methods are applicable, even though the clarification of some specific aspects of the risk assessment is still required.

2. BACKGROUND AND METHODOLOGY

The non-formal educational activities aimed to the transferring to students the necessary knowledge and awareness of the importance of nanotechnology / nanomaterials for the daily life, together with the introduction of *Responsible Research and Innovation* (*RRI*) dimensions [2]. In this respect, the *Industrial Applications of Nanomaterials* Unit has been designed and included as part of the thematic Romanian IRRESISTIBLE Teaching Module entitled: "*Nanomaterials and its applications*".

The Module aimed to develop to students a series of cognitive competences (knowing and interpreting the knowledge, using and understanding the specific language), by introducing educational methods (inquiry, problem solving, critical and constructive reflecting, creative behavior). The cognitive competences have in view the acquisition of proper knowledge related to the concepts of nanotechnology and nanomaterials, the illustration of a series of present applications emphasizing on the importance of using nanotechnology for the human progress, the possibility of giving examples related with the application of nanomaterials in the industrial products, expressing judgments regarding the need to know the importance, benefits, risks of using nanotechnology in the everyday life. Most of the "*Nanomaterials and its applications*" Units introduce everyday life situations, but also relevant topics for primary and secondary students, by using the *Inquiry-based Science Education* strategy and addressing *RRI* issues [3].

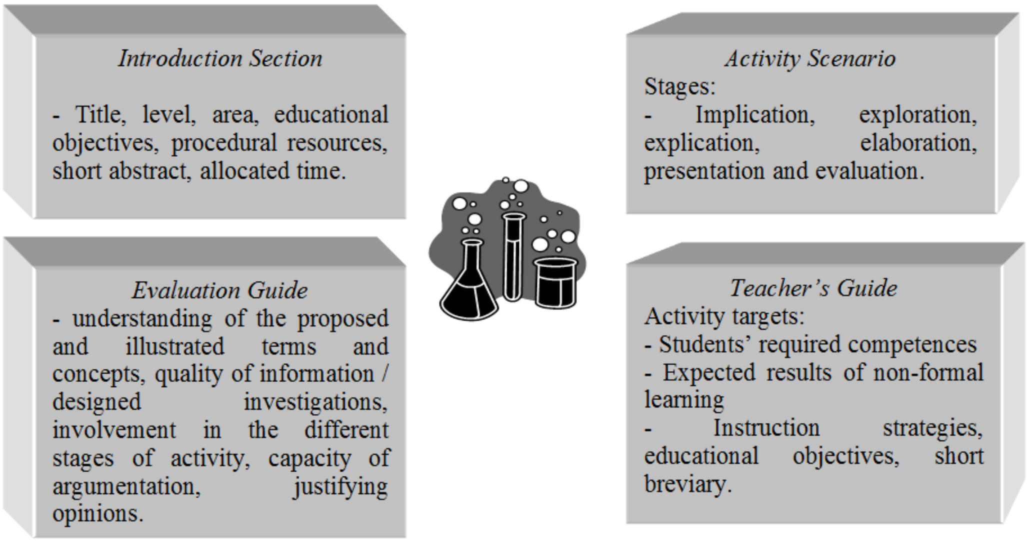

Figure 1. General structure of the Industrial Applications of Nanomaterials Unit.

As it can be seen in Fig. 1, the Unit is structured in four main sections: *Introduction*, *Activity Scenario*, *Teacher's* and *Evaluation Guides* which are briefly described below, considering the introduction of RRI issues. In the *Introduction* section, there are stated methods and processes used as procedural resources for the non-formal activity (conversation, explanation, observation, investigation, reflection, case study, learning through discovery, brainstorming, structured academic controversy), but also the main educational objectives:

- Defining, classifying and identifying of the main characteristics of nanomaterials;
- Identifying the types of nanomaterials suitable for industrial applications;
- Establishing the correlation between the structure and properties of different nanomaterials;
- Exemplifying the use of nanomaterials in various industrial fields;
- Explaining the importance of the applications of nanomaterials in industry;
- Presenting, in written form or orally, of the results of the proposed investigation, using specific nanomaterials terminology;
- Arguing the advantages and drawbacks of the current and future technologies for the environment, as well as the analysis of the consequences of the use of nanotechnologies for the society and environment;
- Expressing personal opinions, coupled with responsible attitudes with regard to industrial applications of nanomaterials;
- Taking optimal decisions about the use of nanotechnology in practice.

The *Activity Scenario* is divided in several stages (Table 1) of non-formal activity, combined with the introduction of RRI issues:

Table 1. The non-formal activity stages.

Stages	Proposed activities	Non-formal learning activities
Engage	- Investigating of a real-life situation; - Formulating hypotheses and planning investigations; - Defining the working teams; - Presenting informative materials in a digital environment, where the actual results of applications and research related to nanomaterials in industry are illustrated.	- Discussing about how nanomaterials / nanotechnology are valued in our society; - Generating a list of areas of industrial applicability, and record them on the board; - Mentioning positive aspects, as well as negative ones, concerning the use of nanotechnology and recording them on a board.
Explore	- Presenting the necessary aspects for deliberation; - Presenting the worksheets with information about the areas of the industrial applicability of nanomaterials (for each team).	- Thinking to the problems that arise from the point of view of the working groups (in relation to the field / fields of industrial applicability); - Group reflection, oriented on defining the problems to be investigated and an action plan; - Identifying stakeholders, establishing relevant facts, formulating questions, determining the problems/concerns of each involved parties and proposing possible solutions; - Defining the concept of *ethics for students*, with an emphasis on the idea of morality; - Submitting the fundamental rights which may be violated or which may come into conflict each other.
Explain	- Explaining the elaboration of the individual report.	- Drawing up of a report (by each member of the group) that summarizes its own opinion (as expert) regarding the appropriateness of the use of nanotechnology in the field / fields investigated by the group.

Table 1. The non-formal activity stages (*continued*).

Elaborate	- Asking students to share individual conclusions and arguments; - Drawing a group report (by students) that presents the assumed decisions and the corresponding arguments.	- Presenting the arguments identified by each student in the group; - Investigating (by each group) the implications of nanomaterials applications in the selected domain / domains; - Deliberating (by students), using the Structured Academic Controversy (SAC) method.
Dissemination / Exchange / Presentation / Display	- Asking students to present the final decision concerning the proposed issue; - Asking students to present the final product - the Group Report.	- Setting the final position of the group, supported by the most relevant arguments; - Drawing up a collective report (Group Report), which reflects the position of the working group; - Presenting to colleagues (by each group) the final decision.
Evaluate	- Asking students to express personal opinions by answering to the proposed questions; - Answering to questionnaires (self-assessment grid, feedback questionnaire).	- Responding to the proposed questions; - Filling-in the questionnaires (self-assessment grid, feedback questionnaire).

The *Teacher's Guide* points out what are the students' competences needed to be acquired, expected results of non-formal learning, instructional strategies, educational objectives, illustrating also a short breviary related to the Unit thematic. The designed non-formal activities allow students to acquire / to form new knowledge, skills, attitudes etc. aiming to:

- Understanding the definition, classification and characteristics of nanomaterials;
- Identifying the appropriate types of nanomaterials for industrial applications;
- Exemplifying and understanding the importance of nanomaterials applications in various industries;
- Presenting, in written form or orally, the results of investigation, using specific nanomaterials terminology;
- Reasoning for the advantages and drawbacks of the current and future technologies for human and environment.

The expected results of non-formal learning will allow the students to argue on the importance of nanomaterials in industrial applications, based on their characteristics, making also correlation related to structure-properties of different nanomaterials and presenting the advantages of using of those kinds of materials. The students can express a personal view on the impact of nanomaterials usage on the environment, and present the products of their activity in the format of *ppt* presentations / posters or mini-exhibitions, in which they have to capture current concerns and perspective in the field of industrial applications of nanomaterials. In addition, they can demonstrate abilities and specific skills requested by a generic responsible citizen (to be aware of some of the problems facing the actual society, to express and argue the own opinion, to get involved actively in debates having a civic nature).

The activities subsumed under this theme are based on a scenario that begins with a question (which involves the solving of a problem), while students try to find a suitable answer. The proposed scenario is built as a short problematic story: "*Two school mates were playing. They are advised to stop playing because one of them is called to help his father for washing the car. Another one looks a little bit annoyed; due to the fact that he finds that his friend family car should be washed more often than the car of his parents and tells him that his car is washing itself*". The question is: *on what basis, the students made that statement?*

The proposed activities exploited the prior knowledge that students gained at Biology, Physics and Chemistry lessons, aiming through defined educational strategies, to acquire skills for the exploration and investigation of the environment, but also to develop analysis capacity and synthesis, personal skills, communication and relationship features. During the activities, the students become familiar with a number of concepts related to the behavior of various nanomaterials and their particular applications in various fields of interest. The suggested strategies are based on: methods and processes (conversation, explanation, observation, investigation, reflection, case study, learning through discovery, brainstorming, structured academic controversy), forms of organization (groups, frontal, individual), material resources. By promoting the *Inquiry-based Science Education* strategy, the students form/develop skills and capabilities of exploration and investigation, communication and effectively working in groups, analysis and synthesis, evaluation and anticipation etc. More, the students become aware of the need to respect the principles and ethical values in research and innovation approaches.

3. RESULTS AND DISCUSSION

During the non-formal activities, the students have been actively involved in experimentation and observation, but asking also for guidance and supporting information from participating researchers and experts. By facilitating the students' access to the information derived from valid experiments, by providing exemplifications near the basic principles on how a certain information can be valorized in the everyday life, the researchers and experts can increase the students' interest for learning, particularly in this case for the *Nanoworld*.

Having in view that the aria of nanomaterials is a bit hard to be understood by the students (mainly due to the fact that nanoparticles cannot be seen without special optical devices or apparatus), the proposed didactic strategies aim to design teaching / learning activities centered on: explanation, experimentation, observation, debate, reflexive approach. The students represent an active part, being engaged in the experimental part, in the investigation-discovery demarches, in the process of searching of information resources - all those aspects being presented in a strong interference with the *Responsible Research and Innovation* (*RRI*) dimensions (issues related to engagement, gender equality, Science education, accessibility, ethics, governance, sustainability and social justice). More, it was noticed that the proposed experiments (e.g. green synthesis of silver nanoparticles, hydrophobic textile, magic sand etc.) in which students had been involved, have greater impact on students' involvement and curiosity, mainly due to the fact they were initiated from the beginning with the basic concepts of nanomaterials, studied in the Units dedicated to formal education.

In the end, the students were given a series of short questions for capturing the prompt reflection on what they had learned and for promoting the process of learning through discussion. They were also asked to discuss their findings together with reflections on *RRI* issues, in four different groups, each group having as facilitator a teacher or a researcher. The groups were formed function of the investigative theme, being linked with one particular area: (a) *Consumer goods* - Working Group 1; (b) *Military* - Working Group 2; (c) *Food and Medicine* - Working Group 3; (d) *Building materials* - Working Group 4. The RRI issues arose in conjunction to the answers to the following questions or tasks:

- Do you consider ethical the creation of new materials, rearranging so the matter in a practical way?
- List a series of applications based on nanomaterials that you consider important in the consumer goods industry / military domain / food and medicine areas / building materials sector.
- Put yourself in the position of a businessman: what business opportunities can you identify in connection with the use of nanotechnology in the field of consumer goods / military / food and medicine / building materials?
- Indicate a series of advantages and disadvantages related to the use of nanotechnology in the field of consumer goods / military / food and medicine / building materials.
- What could you do if you were a person with responsibilities in relation to: legal aspects of the use of nanotechnology, opportunities created by the development of nanotechnology, possible funding of research in the field.

400 students were asked whether those kinds of demarches, which include discussions and reflections involving RRI dimensions, are welcome during the non-formal activities that propose scientific topics. A great percentage of the questioned students (87%) consider that *RRI* issues have to be retrieved in the context of such non-formal activities (Fig. 1). This may be explained by the previously classroom interventions made by the participated teachers, mostly considering the integrated approach of Sciences in the teaching-learning process. In that context - specific for Science Education - the teachers were focused on raising the students' awareness regarding the ethical aspects that must accompany any research demarche [4].

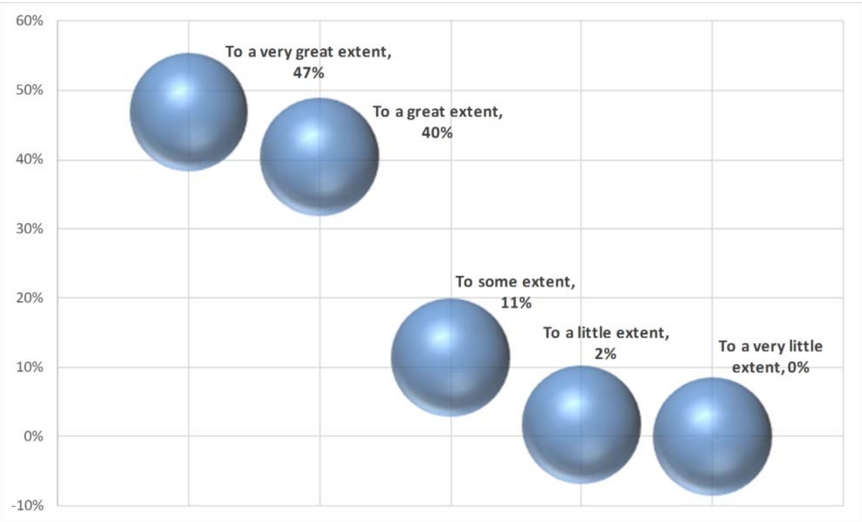

Figure 1. Students' feedback concerning the introduction of RRI issues in non-formal educational activities proposing scientific topics.

The students were also asked whether they are interested to participate in non-formal activities, targeting on RRI issues. Discussions concentrated on treating problems related to engagement, gender equality, accessibility, ethics, governance, are not common (in Romania) during the formal Sciences classes (Chemistry, Physics, Biology), so, the non-formal educational activities represent a good opportunity for raising the awareness about the relation *research- society* among young generation, considering that RRI in Science education helps on “maximizing the creation of shared value.” [5].

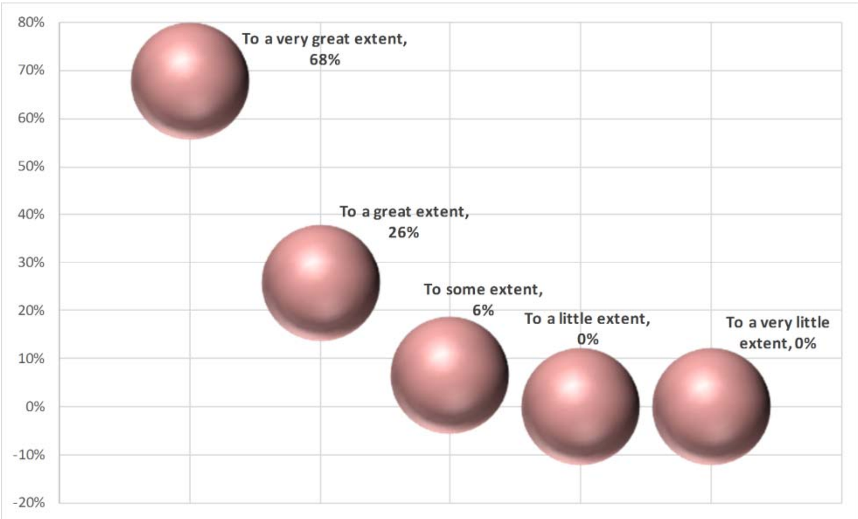

Figure 2. Students’ feedback concerning their interest for participating in non-formal activities which involve discussions on RRI issues.

As “non-formal learning is embedded in planned activities not always explicitly designated as learning - in terms of learning objectives, learning time or learning support -, but with an important learning element in its content” [6], the teacher has a multitude of possibilities to imagine various learning situations, instrumenting also a rich repertoire for practical abilities, consolidating so the theoretical information. For a teacher, it is not an easy task to interfere scientific contents (pointed out by a strict curriculum) with RRI issues, but - as the 2013 *Eurobarometer* [7] related to *Responsible Research and Innovation, Science and Technology* stipulates -, “evidence shows that European citizens (young and old), appreciate the importance of Science and want to be more informed” - those citizens expressing their “broad support for Science education, together with an actively promotion of the respect for European ethical principles for conducting scientific research”. In this respect, the students’ feedback concerning their interest in such activities is more than encouraging (Fig. 2), 96% of them considering as a strong one, stated as “*to a very great extent*” or “*to a great extent*”.

However, it is difficult to project non-formal activity-packages where all the RRI dimensions can be introduced, this kind of demarche requesting preparation and iterations. As example, Fig. 3 illustrates the students’ perception related to how the RRI dimensions have been addressed. In this case, the whole activity can be declared as a success, considering the big proportion of students who stated that most of the RRI dimensions were discussed and analyzed in a great measure.

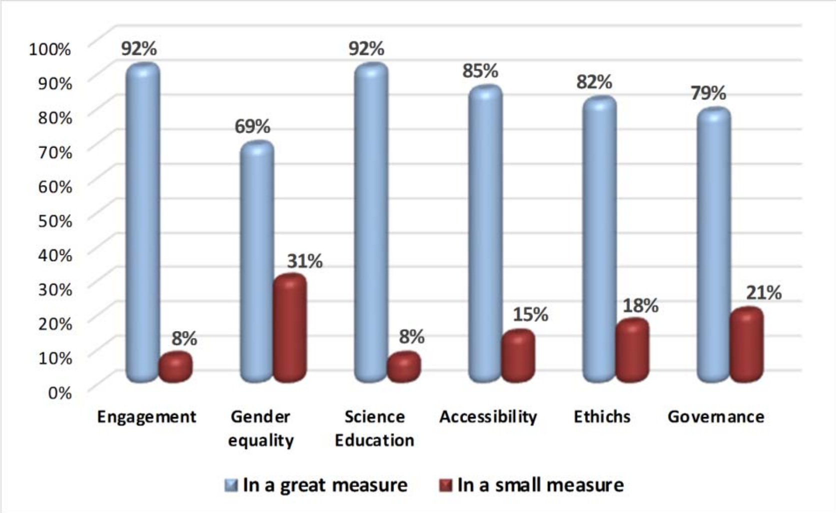

Figure 3. Students' appreciation related to the measure in which the RRI dimensions have been addressed during the non-formal activity.

4. CONCLUSIONS

It is obvious that an educational process undertaken in non-formal settings adds real values to the learning results and complements the formal ones. Education in the non-formal environments can valorize the RRI dimensions, by the adequate use and exploitation of the methods of stimulating learning at the trainees' levels 8]. In the presented case - *Industrial Applications of Nanomaterials* - the introduction of such theme during a non-formal activity represented a success, mostly due to the imposed pedagogical steps, to the gradually presentation of the scientific concepts, but also to its novelty and attractivity. More, the multidisciplinary approach, involving mixt teams (teacher - expert or teacher - researcher) had impact on students, enhancing their interest, curiosity and active involvement in the learning process. Both teachers and students who participated to the activity underlined that such scientific approach has a stronger impact comparative to the classical approach, organized in formal settings.

In Europe, starting with *Rocard Report* [9], it is emphasized the need to revitalize the teaching of scientific disciplines in schools, being recommended new approaches and strategies (as *Inquiry-based Science Education*) to be broadly introduced in practice, the teaching being conducted mainly through inductive (rather than deductive) methods. In this respect, the promotion of various *hands-on activities* in order to allow students to see and feel Science for themselves and to explain what is happening around them in the real life, is crucial - in that way, the understanding of the theoretical issues becoming more facile. Non-formal activities enrich the learning acquisitions made in the formal settings, and as the target (in nowadays education) is to prepare also responsible citizens for the society, the RRI issues must be integrated in the demarches that envisage the presentation of scientific topics. As shown, nanoscience and nanotechnology offer such opportunities - bringing "*nano*" into the learning environments means the students' meeting with the latest cutting-edge Science topics, but also discussing about very exciting future scientific developments.

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