Didactic Proposal to include Nanoscience and Nanotechnology at high School curriculum linking Physics, Chemistry and Biology

Nayareth Quirola¹, Valentina Marquez¹, Silvia Tecpan¹, Samuel E. Baltazar¹²

¹ Physics Department, Universidad de Santiago, Chile
² Center for the Development of Nanoscience and Nanotechnology, Universidad de Santiago, Chile

Abstract. Science and technology at the nanoscale is an important field, not only in modern science, but also an economic activity of vertiginous growth, and therefore, nanoscience should be included as a solid part of the educational curriculum. An interdisciplinary didactic proposal is presented to incorporate nanoscience and nanotechnology (N&N) at the current Chilean high school curriculum. Throughout the didactic sequence, it is expected a better understanding of the science courses followed by the students and, at the same time, of the fundamental concepts of N&N, identifying their benefits and risks to the society with a critical view. This article presents the steps followed in the design of the didactic proposal and characteristics of the learning activities, as well as the methodology foreseen for its validation. Possible risks for the implementation of the proposal are discussed.

1. Introduction

Nanoscience and nanotechnology is one of the fastest growing areas of scientific knowledge, leading to a major impact in the global economy. The presence of more and more products within reach of any citizen, make it necessary to promote literacy in N&N that has been called nanoliteracy [1]. Additionally, the current educational materials of Nanotechnology are mainly available from introductory to advanced levels at the scientific community [2]. However, the access of these contents to the rest of the community is very limited and mainly focused to outreach activities [3].

There are several authors arguing that it is not enough for a nation to direct its efforts to the development of research and applications of N&N. It is also necessary to instruct its citizens to make well-informed decisions, regarding the consumption of nanotechnology products, support of new research projects and participation in public debates on these issues [1, 4-6]. According to scientists, politicians and business leaders, nanotechnology is conceived as the beginning of the next great industrial revolution [1]. Therefore, it is necessary for the citizens to develop a critical vision of the potential benefits and risks that this technology offers, since ignorance unnecessarily increases the perception of risk [4-7].

The scientists involved with nanoscience and nanotechnology agree that it is necessary to include these contents within the curriculum of secondary and elementary education [5, 8, 9], not only as dissemination activities but as an intended formal education in N&N. It implies that educational policy
makers must establish a systematic and deliberate effort to promote changes to the official curriculum. This process could be long, because it requires the consensus of different members in the educational system [10]. Therefore, an option to immediately integrate N&N contents is to incorporate them into the current school science lessons as a contemporary and motivating theme for the new generations of students who have already heard concepts of nanotechnology at informal educational environments [6, 9].

The emergence of nanotechnology has implied that dissimilar disciplines are merging and converging at the nanoscale to develop innovative applications. However, even within the academic community, knowledge of N&N is often fragmented. It is necessary that the didactic proposals reflect the trans-, inter-, and multidisciplinary nature of this field of knowledge, showing the convergence, not only between the exact sciences, but also with the social sciences through the Science, Technology and Society (STS) framework [1].

One of the main advantages of including N&N to the current curricula of secondary school is to give an interconnected view of Physics, Chemistry and Biology courses throughout the different concepts and applications of N&N, providing a more comprehensive view of these courses to the students.

2. Teaching proposals in nanoscience education

Nanotechnology educational programs are recently designed [8, 9], and theoretical framework is still an ongoing work. These features are important because of the necessity to explain the methodological and content decisions to be included. The advances in science education are helpful to introduce N&N and some agreements have been reached [6].

There is a consensus about the need to develop teaching proposals on nanoscience with a solid foundation in the basic knowledge of school science, mainly in physics, chemistry, biology and mathematics [1, 3, 10]. It also coincides with the need to incorporate elements of applied sciences such as technology of materials, environment and medicine, among others [11]. However, it is less common to find proposals that incorporate the view from the social sciences and the humanities [1, 9].

The amount of didactic proposals increases as the school level increases, so there are few proposals for elementary school, more of them in high school and still more at higher levels [9, 10]. This might be due to the level of abstraction necessary to understand the laws present at nanometric scales [11]. However, experts also agree on the need to begin with nanoscience education from elementary education [10].

Although there are many nanoscience learning resources available on the Internet with interesting demonstrations or experiments, these are not part of a didactic sequence. Additionally, many of them require purchasing special equipment or material, so it is difficult to adapt some of them to different contexts [6].

2.1. Didactic proposals in nanoscience and nanotechnology in Latin America

In Latin America, there are fewer nanoscience training initiatives than in English-speaking countries. Particularly, in Chile, until 2011 there were only two training initiatives in nanoscience for elementary and secondary education, however, they were not supported by textbooks or manuals for their teaching, because at that time, there was no record of any corresponding literature on the subject [10].

Regarding the training of high school science teachers, only two of the Chilean universities have incorporated nanoscience topics, suggesting that only a few high school science teachers are trained to teach N&N. The lack of initiatives for the training of science teachers in nanoscience by universities might occur because currently nanoscience education in high school is partially included only in the academic curriculum [12] and within an elective course (Chemistry) [13], implying that few teachers
are required with this preparation. As a consequence, the students choosing educational programs have marginal options to get nanoscience education.

At the Latin America region, five didactic proposals on nanoscience training were found at secondary education level. It was found that four of them are not linked to their current scholar science curriculum, and only one establishes the need to link nanoscience contents with curriculum, but does not indicate how to do it. From this we can infer that, at regional level, there is no general criterion of didactic orientations about how to introduce contents of N&N in the courses of sciences, specifically at high school [10].

One of the contributions of this proposal is that it is based on the current Chilean high school science curriculum. After an analysis process, the precise curricular units were determined to incorporate the contents of N&N in the three science subjects (Physics, Chemistry, Biology) in a sequential and progressive way, linking the three scholar science courses, and favoring that students recognize the interdisciplinary nature of N&N [1].

3. Background

Currently, there is not a Chilean state policy to incorporate N&N education in a coherent and homogeneous way, despite the economic importance that this area of knowledge represents worldwide. This implies that there is not a national strategy to organize and integrate the different initiatives that have emerged from public and private research centers to systematize N&N education [10]. On the other hand, the curriculum of high school is undergoing a process of revision and updating, particularly, the science curriculum of the last two years of high school is being analyzed by the different members of the educational system involved in the scientific education. In this context, the need arises to provide a didactic proposal for N&N education that can be implemented immediately in the current curriculum of high school.

It is expected that in the short term, the proposal can be implemented to get evidence of its usefulness in basic N&N education (This process is explained in the section four). With these results, it will be possible to propose their formal incorporation into the national science curriculum.

3.1 Importance of nanoscience and nanotechnology in Chile

N&N have entered the Chilean market through different companies, however, there is currently no long-term government policy for the development of N&N. It is necessary that the government gives priority to the promotion of local nanotechnology and, therefore, the resources and guarantees necessary for a greater production of Research and Development (R&D) done in Chile. This would mean for Chilean science and technology a significant impact towards the technological transfer of innovation processes of the productive sector in general. In a country with a rich diversity of natural resources such as Chile, the N&N would be able to raise quality standards to become a technologically independent country with added value, since nanotechnology can be applied in a myriad of materials, improving results of use and application [11].

3.2 N&N in the high school sciences curriculum Chilean

In Chile, at high school, students can choose between vocational education and academic education. In the year 2010, approximately 54% of students in the last two years of high school selected academic education [12]. Currently, N&N education in high school is limited to those students who choose the curriculum of Chemistry, which is only available for academic education. This limitation implies that there is a small proportion of students who have access to N&N education. Furthermore, N&N is included as a content in the Chemistry curriculum, but there is no learning objective for that content. This could happen because of time constraints for an extensive curriculum [13].
The scientific curriculum for the last two years of high school is undergoing a process of revision and updating. This current curriculum, which includes N&N content for a small proportion of students, will remain in place until 2020 [14], making it necessary to start with N&N education in high school as soon as possible. Waiting for the new national science curriculum implies to stop training the current generations of high school in the big ideas of N&N [5].

4 Characteristics of the didactic proposal

The design of the didactic proposal presented in this paper was carried out following the stages of the process presented in Figure 1. The goal of this proposal is to increase the understanding of the current contents of the three school sciences, and at the same time, of the big ideas of N&N [5]. In this context, the first stage was the analysis of the current science curriculum looking for contents related with N&N. In the next stage, the theoretical advances of N&N education were analyzed [15]. Right away, on the next stage, different educational resources of N&N were analyzed evaluating their pertinence and usefulness. In the fourth stage, the design of educational resources was carried out. These educational resources are in context with the Chilean reality. In the next stage was designed the didactic sequence, in order to advance progressively in the basic N&N knowledge. The level of difficulty of the proposed activities advances progressively along with the proposal. Finally, in the last stage, a teacher’s handbook was developed with the basic instructions to understand and carry out the learning activities included into the didactic sequence, even when the teachers are not training in N&N education. At this moment, the design process is finished.

![Figure 1. Design process of the didactic proposal to incorporate N&N in high school.](image)

Currently, the proposal is in a process of validation through an expert judgment. The validation results will be used to make the relevant adjustments on the didactic proposal [4]. Subsequently, a training workshop will be held for teachers interested in the implementation of this proposal. Once the stages are completed, the implementation will be carried out (see Figure 2). It is hoped to obtain evidence of the achievement of the learning objectives for both, science subjects and N&N big ideas [5, 15].
Figure 2. Next steps after validation of the didactic proposal to incorporate N&N in high school through an expert judgment

4.1 Relationship between the didactic proposal and the current high school science curriculum.

After a process of analysis, the precise curricular unit was determined to incorporate the contents of N&N (see Figure 1). The third unit of the last year, the science curriculum of high school allows to incorporate in a sequential and progressive way the contents of N&N. In the three subjects of school science there are contents that are related to N&N. In Physics, we have the curriculum unit “The atom and its nucleus”, while in Chemistry, the curricular unit is called “Polymers” and in Biology, the curricular unit is “Immune system”. The proposal to incorporate N&N advances progressively starting in Physics, then continuing in Chemistry and finally concluding in Biology. The N&N contents developed in Physics will be used in Chemistry and later in Biology. The experts on N&N education agree that it is important to develop the abilities to communicate and to work across and between conventional science disciplines [2].

There are many applications of nanotechnology, for example in the production of active food packaging, or the use of nanomaterials for the treatment of various diseases. In this proposal, Technology, Medicine and the Environment were selected as unifying topics between the subjects (see Figure 3). Additionally, these topics incorporate the STS framework to make evident the relationship between scientific and technological advances with society [7, 11]. It is important that students understand the interdisciplinary nature of N&N. The sequence of activities is designed to make evident the relationship between disciplines [1, 2].

On the other hand, the proposal also intends to promote collaboration between teachers. It is necessary that the Physics, Chemistry and Biology professors organize the previous activities of each course to execute the didactic sequence in the proposed order. The science curriculum of the three courses is extensive. Based on this, the proposal has only 90 minutes of face-to-face work assigned to learn the N&N concepts at each subject. They can be two sessions of 45 minutes each or a single session of 90 minutes.
4.2 Themes of N&N included, teaching methods selected and expected learning outcomes.

In this section, we present the different activities developed for each one of the Physics, Chemistry and Biology courses. The activities will be driven to introduce and develop some well-known key concepts of N&N [8]. We have used different educational methods and approaches in the activities because it is necessary to incorporate the different contents of the proposal to the curriculum. These methods are necessary because each unit has specific goals and cover different aspects of N&N. Particularly, we do not need to give an introduction of the fundamental concepts of nanoscience and nanotechnology at each course, prolonging unnecessarily our proposal. Instead of this, we emphasize the collaboration between the courses and cover the main aspects such as Nanoscale (Physics), synthesis and functionalization (Chemistry) and application (Biology) [15]. Additionally, the inclusion of several methods to implement the activities relies in the requirements of various student groups with different needs and realities [8]. The set of proposed activities allows incorporating the STS framework, so the relation with the social sciences becomes evident [7, 11].

First, we present the proposal of Physics, where the fundamental concepts such as nanoscale and surface-volume ratio are given as well as the study of the properties of the materials at different scales. These contents are incorporated in the third unit of the curriculum at the last year of high school. Then, we introduce the main concepts of synthesis and functionalization of nanomaterials in the unit three of the Chemistry program. Finally, a discussion and debate activities are prepared at the end of the unit three of Biology to include the consequences of the application of nanotechnology.

4.2.1 Activities in Physics

In the Physics course, we have prepared a suitable audiovisual material to introduce the basic concepts of N&N such as nanometer, scale, self-assembly or tunneling effect, top-down and bottom-up views and their consequences. The use of multimedia materials has already been proven to be suitable in the introduction of Nanotechnology to the scholar community [8]. One of the first challenges to introduce nanoscience is related to the concept of scale [6]. We have used a classification activity to associate objects to different world scales, helping the students to explore the perception of the size of different objects. Therefore, the first task of the teachers is to help to the students to identify and classify the different worlds across to the size of the objects. These objectives follow the expected learning of the Physics curriculum “To describe the atomic nucleus and some of its properties”. In this context, we have defined a learning result “To recognize the Nano-world and its dimensions, comparing objects, properties and laws of it with those belonging to other worlds”. The corresponding activity consists in
to classify objects inside of a scale: Macro-world, Micro-world, Nano-world and subatomic scale.

The next topic is related to the properties of the materials at nanoscale. Here the first activity is to identify the constituents of the atom, and the evolution of the atomic models. The second activity is related to the surface-volume ratio concept [15]. We propose a hands-on math activity, where the students calculate geometrical features of materials, such as surface area, at different scales [6, 9]. Here the students will explore how the differences in the scale leads to differences in materials properties such as reactivity. This is achieved evaluating the surface area of a cube being cut in halves and associate the increased surface area to the reactivity of the material.

Finally, with the help of a short video, we can introduce the tunneling effect, which is a concept of quantum mechanics and very useful in the characterization of nanostructures [15] (see STM in Chemistry section). We summarize this section with a mind map activity, where the main concepts and vocabulary are included. This visual aid will be helpful for the students in the following courses.

4.2.2 Activities in Chemistry
The proposal is incorporated in the Chemistry curriculum at the end of the unit three “Polymers”, where the expected learning “To present remarkable polymers at industrial processes such as clothes production and plastics identifying their importance in the society”. From the expected results, we have defined “To identify the use of N&N in the production of plastics, declaring their benefits and risks to the society”.

In this section, we must consider the previous knowledge obtained from the introduction of N&N in physics section (Nanoscale, surface-volume ratio), as well as the contents of the Chemistry curriculum dedicated to polymers. The first part of this module is focused to the fabrication and functionalization of nanopolymers. The first activity considers the introduction of carbon nanotubes from the geometrical construction and their mechanical, electronic and chemical properties [8, 9, 15]. We propose the application of a hands-on activity, where the students build a representation of nanotubes from a sheet with a hexagonal pattern. This activity will be complemented with a description of the properties of nanotubes as a function of their geometric construction [8].

The second part is devoted to the characterization of the nanopolymers, emphasizing the development of tools to “see” and manipulate nanostructures. The first activity shows an analogy of how the scanning tunneling microscope (STM) works, through the sensing concept applied to different properties [6, 9, 15].

The next activity is related to the functionalization of nanotubes with polymers by an interactive representation of the creation of active sites and formation of different bonds. We propose a role-playing activity, where the students will represent the functionalization of nanotubes with different polymers. This resource has already been implemented in undergraduate biology classroom [16], as well as physics teachers training [17], and helps improving the explanation of several processes to the students, focusing in their memory-oriented learning abilities through the visual representation of the functionalization processes.

The following activity is intended to identify the usefulness of nanostructured polymers in society according with the STS framework [7]. The students will extract information from a newspaper column related with the application of nanopolymers in the national food industry. The last activity for this module focuses on the identification of nanomaterials of different commercial products. The students should relate the properties and applications of these nanomaterials with the characteristics of the product.
4.2.3 Activities in Biology

This proposal is focused in the application of nanotechnology to biological systems and will be incorporated at the end of the third unit in the Biology curriculum “Immune system: diseases and treatments”. The previous knowledge requires the concepts already covered in the physics and chemistry sections (nanoscale, functionalization, etc.), along with the formal content of the original curriculum (immune system). As a learning result of this section, the students should be able “To analyze the risks and benefits of N&N to the society, particularly, in the application to medicine and treatments autoimmune diseases”.

We are considering two activities. The first one corresponds to the search and critical discussion of several information sources related to three topics: “Use of vaccines with nanotechnology in the treatment of human immunodeficiency virus (HIV)”, “Nanotechnology in the cancer treatment” and “Transplant treatment with Nanotechnology”. The students will prepare a report based on the provided literature, identifying nanomaterials, benefits and risks of these technologies, as well as the reliability, objectivity and relevance of the sources. Through this activity, the students will investigate the benefits and risks involved in the application of nanotechnology at health area.

Finally, at the biology section, we have included a debate activity in classroom, based on the benefits and risks of nanotechnology applied to diseases treatments [1, 7]. This method is focused in the discussion and identification of arguments proposed by different students groups [18, 19]. The class will be divided in three groups: Moderator (teacher), jury and experts (in favor and against the proposed topics). At the end of the activity, the teacher will give closing statements to emphasize the different aspects of nanoscience (scale, interdisciplinary, etc.) and their effects in the society, considering positives and negative aspects, as well as the necessity to acquire the basic knowledge on N&N to make well-informed decisions.

4.3 Teacher’s handbook

One of the main difficulties to implement this proposal is related to the lack of scientific knowledge in nanoscience from the teachers, because most of them were trained before the inclusion of N&N in the science educational programs [20]. This is especially important in Latin America, where the inclusion of nanoscience to the educational program of science teachers has been only recently incorporated at specific curricula [13]. As part of the proposal, a manual was developed for the teacher with all the instructions to effectively implement the didactic proposal. Each learning activity is described in detail and additional information is provided, so even teachers with no formal education in N&N can guide learning activities. Our proposal includes not only the worksheets with completed learning activities for each unit, but also it has additional comments to implement the activities, suggested answers and expected conclusions given to the teachers. In this context, we have included a suggested assessment for the learning activities. This is helpful to identify the learning level reached by the students, as well as the achievement degree of the expected goals for each activity.

4.4 Validation Strategy

We choose expert judgment as validation strategy [4]. To validate the scientific contents as well as the educational goals of the proposal, we have considered the evaluation of our proposal from two groups: scientific researchers of Physics, Chemistry and Biology, and high school teachers of the corresponding areas. In the case of scientific evaluation, the researchers are also involved in different topics of nanoscience and nanotechnology, and their feedback will be important in order to get current definitions, concepts and state-of-art applications for each course. From the teachers, we will get the
useful comments related not only to the implementation of the activities and the evaluation of the level reached by the students, but also the feedback of the appropriate inclusion of the proposal at each class to follow and complete the objectives of the Chilean curricula.

5 Discussion and Conclusions

This proposal is characterized inside the Chilean curricular discussion process at the scientific basis of education. One of the main strengths of this proposal is its adequate application into the educational curricula, due to its abbreviated extension, not only keeping its contents, but also supporting the current curriculum of each science course. The inclusion of N&N into the secondary curricula is an important aspect that has been previously considered at N&N [9], but considering only two specific activities in Physics and Chemistry. In our case, the interdisciplinary characteristics of N&N make it suitable to incorporate into the sciences courses of secondary school, e.g., the nanoparticles are defined in Physics and later applied in Biology, or properties changes proposed in Physics are later incorporated in carbon nanotubes discussed in Chemistry. Because of these connected topics, a more comprehensive view of the science course is expected, and additionally the Science-Technology-Society (STS) aspects are included because of the contents in Chemistry and Biology related to environment and medicine.

In Physics, we propose, based on the theoretical framework of nanoscience education [6, 15], as a learning result: “Recognizes the nanoworld and its dimensions, comparing the objects, properties and laws that belong to it and those belonging to other worlds”. This could be achieved through the proposed learning activities. At the same way, in Chemistry we propose as a learning result: “Identifies the use of nanoscience and nanotechnology in the production of plastics, declaring its benefits and risks for society”. Finally, in Biology the proposed learning result is: “Analyzes the risks and benefits of nanoscience and nanotechnology in society by discussing their use in medicine for the treatment of autoimmune diseases”.

The use of different educational methods is an important aspect in order to capture the attention and to stimulate several groups of students with different interests. These methods have been previously applied at high school level and were discussed using a Delphi study [15].

The proposal is easy to apply from the point of view of its extension since it requires only 90 minutes for each science subject. In addition, it supports and complements the current contents established in the curriculum. However, there are some risks to its implementation. These are: a) lack of education in N&N by teachers and b) difficulties with teacher’s coordination resulting from collaborative work between subjects. The didactic proposal includes possible actions to minimize these risks.

Finally, the revision of our proposal is currently underway by science teachers and scientific experts. Once we have collected and revised the feedback from the reviewers, we will follow the implementation process (see Figure 2). This will consider a workshop for teachers focused in the implementation of this proposal in classroom, and finally the analysis of the implementation results. We agree on the need to improve N&N training programs for high school science teachers [1, 3, 10], making this didactic proposal a useful tool to achieve this goal.

The authors thank the support of the Basal funding for Scientific and Technological Centers under Project FB0807. Also, S. E. B. would like to thank the support of DICYT under the grant 041631BR and the PID-USACH project 051-2016.

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