NANO_MET: A NANOMETROLOGY SIMULATION APPLICATION FOR TEACHING

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Abstract. This work presents an educational web application about dimensions and properties related to nanomaterials. The application brings information through a simulated experience with the presentation of nanomaterials images in 2D, 1D and 0D formats. Comparisons between objects of different sizes are also made, allowing to approach the basic notions of metrology, such as magnitudes and scales. As an educational resource, it helps in learning and discovering the properties and applications of nanomaterials related to the change of scale and its consequences in an interactive way. The scope was limited to carbon nanomaterials in order to meet the objectives more efficiently. The validation was done using the inverted classroom model with a post-high school technical course class. The validation process showed that the application, besides serving as an educational resource for high school classes, can be extended to several classes or even to the general public, and is also suitable for learning methodologies that incorporate new technologies.

1. Introduction

Despite the importance and impact of nanoscience and metrology in the daily life and future of our societies, they are still little known and discussed. Bringing these inter and multidisciplinary themes in the school environment as an important step for their knowledge in society is the contribution that is sought through the application Nano_Met presented in this work. The concepts brought along the app cover several areas of the Common National Curricular Base (CNCB) and addresses fundamental basic concepts in various subjects [1]. By understanding the notion of "nanometry" as it is defined, this app allows the student to reinforce the concepts of the exact science subjects, such as mathematics and physics, as well as understand their impact on society and their role in history. Nano_Met can serve both as a bridge between the school and the society and as a link that connects the humanities, the environment and the exact science subjects in the school environment [2].
Nanometrology is a field of study and practice that focuses on the measurement and characterisation of objects and phenomena at the nanoscale. It combines principles of metrology with advanced

techniques and instrumentation to perform precise measurements on structures and materials with dimensions in the nanometer (billionth of a metre) range. Nanometrology is essential to advance in several areas such as nanotechnology, electronics, materials science and biotechnology [3]. Despite this importance, there are still few countries that invest in research and dissemination of nanometrology. But, in Brazil, the National Institute of Metrology, Quality and Technology (Inmetro) has shown interest and concern for the issue through the creation of a Center for Nanometrology that takes into account the new reality with new technology[4]. Along with this, the process of disseminating knowledge on the subject must be taken into account, either in the school environment or to the general public.

Today's world is characterised by ultra-connectivity and the use of new technologies by all generations. The younger generations are more connected and dependent on digital tools in their daily lives. This touches also the process of knowledge transmission for these generations with the emergence of new methodologies in parallel or even mixed with traditional methods [5]. The present work presents the process of development and validation of an educational application and enters the line of contributions that seek to find solutions and adequate answers to these new challenges.

Taking into account that the industrial model is progressively being replaced by the production and service model based on the knowledge economy, several educational agencies have proposed alternative teaching methods more linked to the current times, seeking to explore collaboration, exploration, investigation and doing. In this perspective, several alternative proposals of pedagogical practices have emerged, such as active learning, where the student assumes a more participatory attitude, in which he/she solves problems, develops projects and, with this, creates opportunities for the construction of knowledge. Several strategies have been used to promote active learning, such as inquiry-based learning, the use of games, Problem-Based Learning (PBL), or Problem and Project-Based Learning (PPBL) [6]. This app, called Nano_Met, could be used as a resource for teaching and learning the basic concepts of Nanoscience and Nanotechnology (N&N), as well as metrology for primary and secondary school students, contemplating the directives of the CNCB in terms of interdisciplinary, transdisciplinary or intradisciplinary approaches, given the scope of both N&N and metrology.

The present work presents an application for modeling and simulation of the measurement/size of nanomaterials (carbon nanomaterials as a base example), its application for teaching and its possible uses for scientific dissemination. It was sought to simulate the measurement of the dimensions of an object at the macroscopic level, as well as simulating the reduction of one, two or the 3 dimensions and comparing the changes in size of the 2D, 1D or 0D nanometric object with the macro or micro size object [7]. And also to observe the changes of properties between the nano and the macro/micrometric object during the process of "nanometrization" (from top to bottom) or "macrometrization" (from bottom to top), such as surface area, electronic and magnetic properties [8]. In order to simulate the measurement and show the importance of the size in the process of the use and application of some nanomaterials and nanoscience in practice, using the examples of carbon nanomaterials.

For the implementation of active methodologies and the inclusion of new technologies in the teaching-learning process, this application will serve as an important aid, not only for the teacher, but also for the student[9][1]. It can also be used directly as a learning object.

2. Materials and Methods

It was developed an educational web application (App web) adapted to mobile phones, so that it was not necessary to download and occupy the phone memory. The development was done in order to allow comparisons between objects of different sizes, thus allowing to approach basic notions of metrology, such as magnitudes and scales, explaining the dimensions and properties related to the nanomaterials. The application brings information through a simulated experience with the presentation of images of nanomaterials in 2D, 1D and 0D formats. For this purpose, it was decided to use carbon nanomaterials for a first contact, so that this contact would be more intuitive and direct, since carbon allows for an interesting starting point from common 3D materials such as graphite, which is used in students' pencils, as well as being able to approach valuable materials such as dynein, which can be a starting point for the general public. Following the categorization presented by Mauricio T. et al. in their review of nanomaterials, where they classify a dimension as nanometric when it is below 100 nanometers, graphene was used as a starting example of a 2D material, since it has one dimension less than 100 nanometers, and in the same logic the carbon nanotube, which has two dimensions below 100 nanometers, was chosen for 1D and finally fullerene, which has all his three dimensions under 100 nanometers, was the initial reference for approaching 0D nanomaterials [10].

2.1. *The Application Development and Use*

The application was developed with various possibilities of use, with an intuitive layout and easy handling. One of the uses is as a resource of information about measurement, since it allows to observe the size of objects from macro to micro and nano. Another possibility is to explore it as a resource of properties, which will allow the user to perceive the changes of properties when it presents the change of size from macro to nano (surface area, quantum confinement, etc.). It can also be a resource of applications, which allows the user to simulate the possible applications that arise from the changes of properties. It also allows the user, through a final questionnaire, to summarise the impressions and knowledge acquired by him and to receive feedback from him with suggestions for improvement, as well as presenting other possible uses for the properties of nano materials.

The examples contained in the app show everyday objects that use nanomaterials, focusing on carbon nanomaterials. Some screens have characters bringing information through conversations in order to draw the user's attention, promoting a playful and fun environment. The link to access the application is here: https://vigorous-elbow-3563.glideapp.io/ . When entering the link, the user will see an initial welcome screen (figure 1), advancing, he finds explanatory screens with contexts and dialogues between the characters in the Application (figures 2 and 3).

Figure 1: Home screen, welcome.

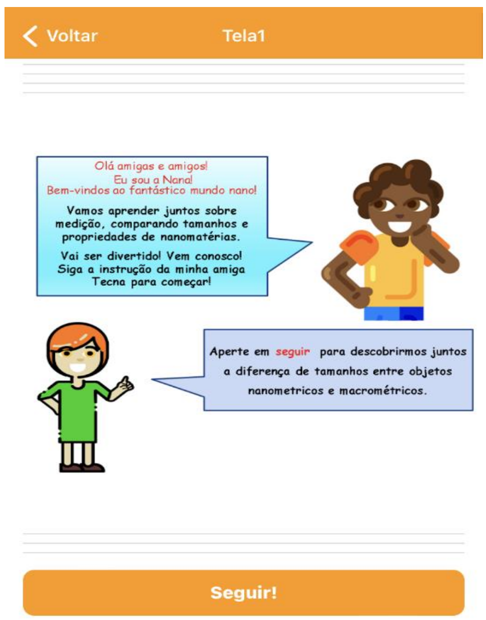


Figure 2. screen 1, dialogues between the characters.

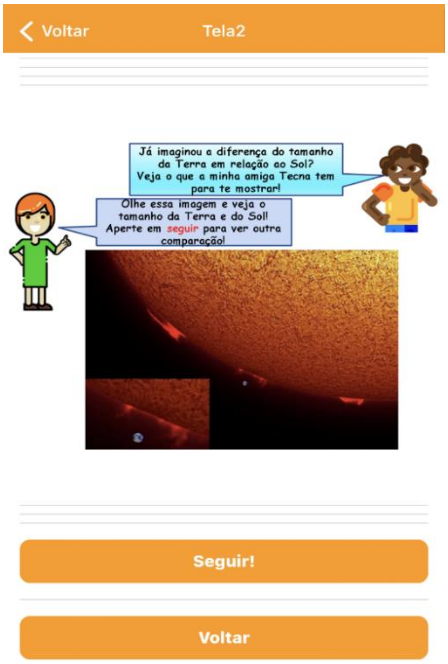


Figure 3. screen 2, dialogues between the characters.

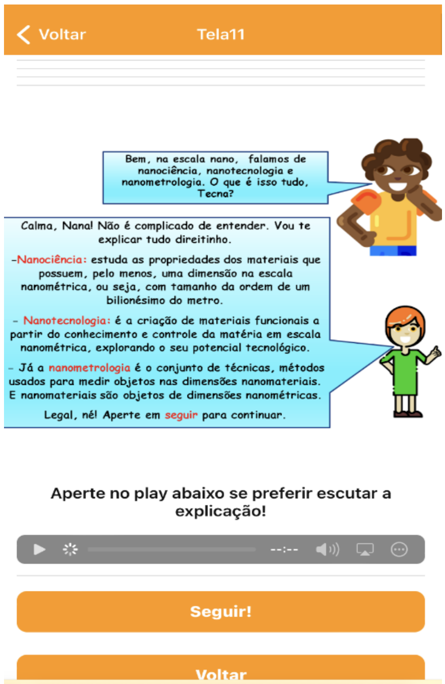


Figure 4. Screen 11, with audio feature.

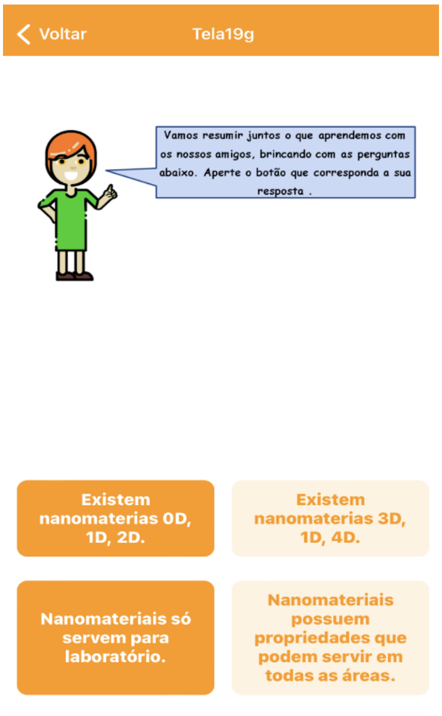


Figure 5. 19g screen, with summary test.

Figure 6. screen 20, with final screen.

In the application itself there are audios with explanations and repetition of the texts of the dialogues to facilitate accessibility for users who are not able to read the text on the screen (figure 4). At the end of the journey, there is a summary test (figure 5). In the final screen, there are three options back to the previous screen, back to home screen, and start again and fill out the form of evaluation of the experience (figure 6).

2.2. The Reversed Classroom for validation

The flipped classroom is an *e-learning* modality in which the content and instructions are studied *online* before the student attends the classroom, which now becomes the place to work the contents already studied, performing practical activities, such as problem and project solving, group discussion, labs, etc. In the traditional classroom teaching, the teacher transmits information to the student who, after the exposure, must study the material that was transmitted and perform some evaluative activity showing that this material was assimilated. In the flipped classroom approach, the student studies before the class and the classroom becomes a place of active learning, with a room for questions, discussions and practical activities. In this case, the teacher should work on the students' difficulties, instead of presentations on the subject content [4].

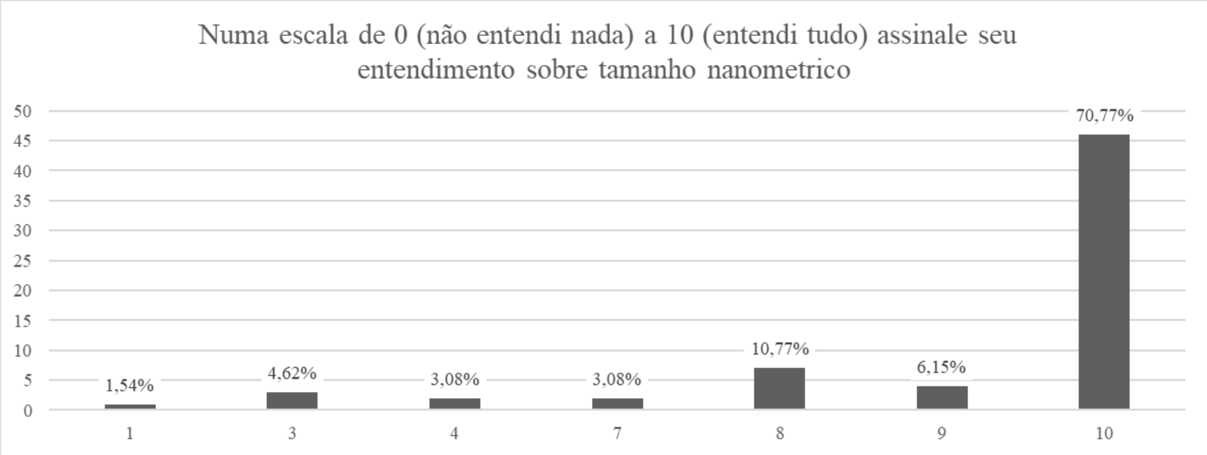
The Nano_Met prototype was validated in an inverted classroom format with the class of a technical course in radiology, in a technical school, in the city of Rio de Janeiro. The students received the application previously and accessed it, which served as background material. When scrolling through the application, they found information and reviewed concepts learned in previous stages of their schooling and discovered new concepts. They answered evaluation questions within the app itself, and, at the end, filled out an evaluation form to summarize their understanding of the topic. The second part of the lesson consisted of a debate between two groups of students where they discussed about what they had understood about the app, and how to improve the dissemination of knowledge about nanoscience and metrology. From the evaluation questions about the understanding of the themes from the application, they were asked to give a score from zero to 10, where zero means they did not understand anything and 10 means they understood everything about.

One of the suggestions made by the students during the prototype validation was to extend the test of the application to people outside the school environment to assess, via the form, their level of understanding. This was also done by the students themselves who sent it to their classmates and acquaintances. It is worth mentioning that people from the general public did not attend any class or participate in any dynamics. Their impressions in the evaluation came from the feedback they gave after their first contact with the application.

3. Results

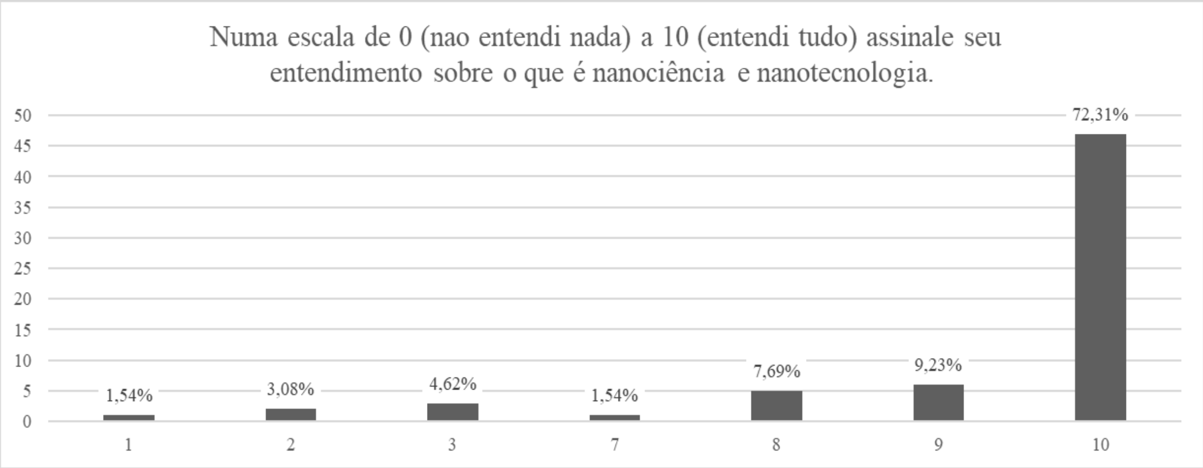
The evaluation of the application counted with a total of 65 people, being 11 students and 54 from the general public.

On the evaluation questions about understanding the topics from the app, the students were asked to give a score from 0 to 10, where 0 means you didn't understand anything and 10 means you understood everything about nano size (graph 1). 100% of the students answered 10, but this percentage drops to 70.8% when extended to general public.



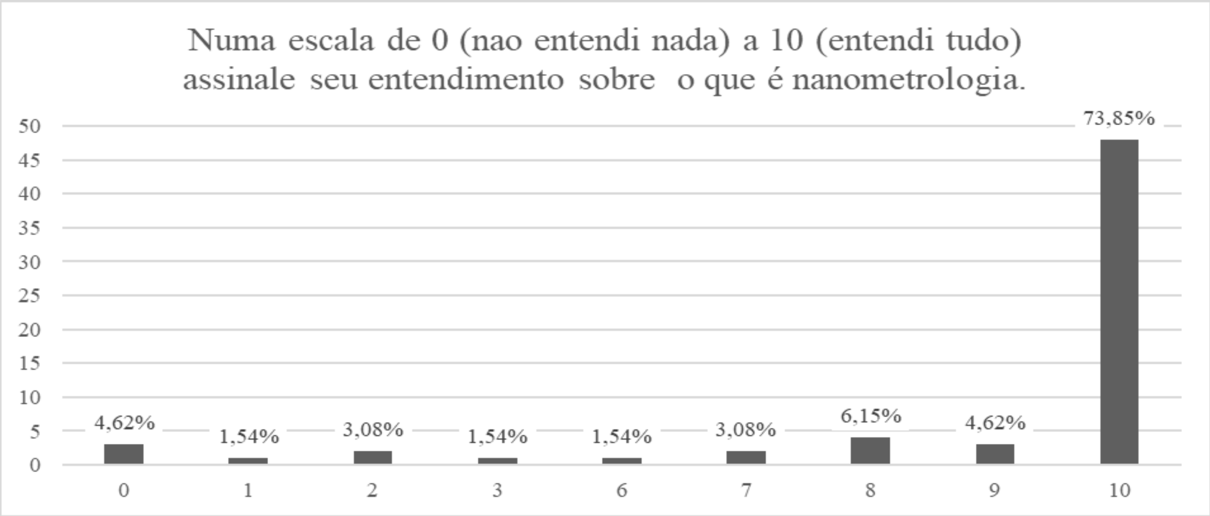
Graph 1. Understanding of nanometre size.

It is noticeable that students in general had a better understanding of the definitions demonstrated in Nano_Met, since 100% of the students answered 10 for the definition of nanomaterial and about the properties of nanomaterials, but this percentage drops to 69.2% and 73.2% (graph 2) when extended to the general public.



Graph 2. Understanding of nanoscience and nanotechnology.

The lowest perception of the general public was regarding the differences between 2D, 1D and 0D nanomaterials, where 100% of the students answered 10, but this percentage drops to 66% when extended to the general public. The answers regarding nanometrology point to a better understanding of this concept in which 73.8% (graph 3) of the general public answered 10; they understood everything about the definition of nanometrology. Although 4.6% did not understand the definition at all, the result was promising. In all cases, the number of people whose impression of understanding was below average (score 5) was not more than 13% (e.g. the difference between the types of nanomaterials).



Graph 3. Understanding of nanometrology.

This final questionnaire sought to pick up the user's impression of their understanding of the topic. The students, who were the target audience and participated in the class, understood and comprehended the topic, probably due to the fact that it had aspects of the subject review and also the discussion of the topic in class, while the general users only had the app. The results indicate that the suggestion of the students to expand it to the general public has some basis, but this should be evaluated at another time.

An interesting point to highlight is the fact that, despite being subjective, more than 70% of the general public understood the definition of the concept of nanometrology. Adding to the good understanding above 70% of the notion of manometric size and the properties of nanomaterials, it can be said that the use of the application as a methodology for dissemination and teaching of concepts of nanometrology proved to be a successful way.

4. Conclusion

The goal of this work was to offer the target audience and their teachers an additional tool that can help in the understanding and implementation of metrology and N&N basics, as well as arising curiosity and interest in these areas. The proposed application was successfully validated through classroom test with high school students in a radiology technical course. The inverted classroom methodology, where the application was used as background material, proved to be effective, but the high rates of understanding returned by the public, who had contact in an environment outside the classroom, showed that Nano_Met can be used with other methodologies and other target audiences. The results achieved demonstrated the use of the application as an efficient Teaching-Learning resource; its use, in the classroom, yielded satisfactory results. Although it was initially developed for students, a specific audience, it showed a great potential to be used by the general public. One aspect to be explored is to work on an application aimed at the general public for the dissemination of knowledge in nanotechnology and metrology.

5. References

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