Nanotechnology as a Tool for Computational Thinking Skills using Open Hardware, Embedded Systems and Repository Platform, in Industry 4.0 Era

Konstantinos Kalovrektis
Dept. of Digital Systems
University of Thessaly
Larisa, Greece
kkalovr@uth.gr

Ioannis Dimos
Dept. of Computer Science and Biomedical Informatics
University of Thessaly
Lamia, Greece
ioadimos@uth.gr

Apostolos Xanakis
Dept. of Digital Systems
University of Thessaly
Larisa, Greece
axenakis@uth.gr

Athanasios Kakarountas
Dept. of Computer Science and Biomedical Informatics
University of Thessaly
Lamia, Greece
kakarountas@uth.gr

***Abstract*—The advancement in Microelectromechanical System (MEMS) technology resulted in accurate and high-performance miniature device systems. These devices are so tiny that they are not noticeable by the human eye and exhibit excellent feasibility in miniaturization sensors due to their small dimensions, low power consumption, and superior performance. The area of science and engineering where MEMS are developed (dimensions in the manometer scale) is called Nanotechnology. Nanotechnology is one of the fastest growing scientific research related to Industry 4.0. Nanotechnology may introduce industrial skills deficits as well as opportunities for new teaching practices in several subjects and educational frameworks. In the present work, we investigate the attitude of STEM (i.e. technology/engineering) and non STEM - related instructors, regarding the integration of Nanotechnology applications in Higher education curricula. Their opinions, concerning the applied teaching method, the learning content material and expected student skills, should always be taken in to account, as they may boost any reformations proposed. Moreover, we propose a repository platform, with which instructors may interact with 3D designs and MEMs material to built their didactic plans. This work's findings is critical for the design and innovative training material and computational thinking (CT) activities, which will prepare student with skills related to Industry 4.0 demand.**

***Index Terms*—Nanotechnology, MEMs, Industry 4.0, Computational Thinking, Open Hardware, Repository Platform**

I. Introduction and Background

A. Nanotechnology in Education

In the past few decades, advances in microelectronic device fabrication technologies have produced compelling, accurate, and high-performance device systems. Technology has been squeezed to the point where we can make devices so tiny that they are not noticeable by the human eye. Microelectromechanical systems (MEMS) involve the innovation of tiny devices that can represent the models as sensors or actuators [1]–[3] and convey data from the nanoscale to the macroscopic scale [10]. In recent times, MEMS technology has grown significantly in acknowledging different sorts of natural sensors and actuators. Besides, it has been utilized in miniaturized sensor manufacturing in a large number of applications due to low power ratings, quick response, ease, cheapness, and better sensitivity [4]. As a result, smarter consumer electronics have opened up new possibilities for citizens in terms of communication, sports, industry, entertainment, etc. The impart of such innovative devices and upcoming revolutionary developments on everyday life, both present and challenge, science and technology education researchers, to incorporate this cutting - edge fields in Higher education contexts [5], [6]. However, several worth noticing issues which emerge and need to be considered, are: [7]:

- To which extend teachers acknowledge the educational and technological significance of Nanotechnology's applications inclusion, within innovative curricula ?
- Do they have all necessary and up - to date teaching material and means to support their STEM activities ?
- Are they well - trained in order to teach modules related to Nanotechnology ?
- Is there a complete learning framework to promote Nanotechnology, as a part into the problem solving process, within the STEM approach ?

In this work we give a quantitative and qualitative explanation regarding the aforementioned issues. Research findings in [8], [9], indicate that teachers' perspectives and attitudes, should be carefully taken into account, in any attempt for curricula change and innovation. Additionally, their opinions regarding teaching methods, learning context and expected

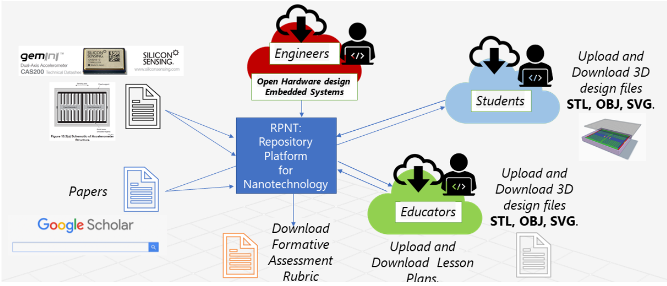


Fig. 1: RPNT: Repository Platform for Nanotechnology

learning outcomes, should be take into account as well, as teachers are considered as the *agents of change* for any potential reformation and innovation [11]. Therefore, the contribution of this study aims to record the STEM and non - STEM related instructors regarding their attitude towards the educational significance of Nanotechnology's inclusion within the new curricula. To do so, we use a five Likert scale questionnaire [25] and we conduct Mann - Whitney U test, as a non parametric test, to investigate the differences in the rank - distribution of the samples. To the best of our knowledge, no similar study relates to such inquiry [7]. Finally, we design and propose and open software - open hardware repository of embedded systems, as a learning design framework, to promote Nanotechnology problems, as a part into the problem solving STEM process approach.

B. Computational Thinking and STEM

Computational Thinking (CT) is undoubtedly considered a fundamental skill as reading, writing, and arithmetic in the 21st century [16] [26], [27]. Janette Wing, in a continuing effort to improve her initial definition of CT, expressed that CT refers to the *mental processes involved in formulating a problem and expressing its solution(s) in such a way that a computer—human or machine—can carry out the task effectively* [17]. Currently, CT has become commonly accepted as a problem-solving method [18] which includes a set of concepts such as *abstraction, decomposition, generalization, algorithmic thinking, evaluation, simulation, verification and predictions* [18], [19], [27]. These concepts mainly arises from fundamental Computer Science and Computing Science practices. According to [26], the dimensions of CT are as follows:

- The ability to think algorithmically
- The ability to decompose an initial problem to smaller problems and to try to firstly solve the smaller ones
- The ability to draw conclusions (i.e. generalize) and to use patterns
- The ability to evaluate a model
- The ability to think abstractly

The majority of European (EU) and non - EU countries, realize the importance and center role of CT in educational activities and adopt CT training into their curricula [11]. Nanotechnology is a interdisciplinary scientific and engineering field, devoted to designing, producing and using structures and systems, by controlling molecules and atoms at nano - scales [20]. Nanotechnology education and didactic activities have to do with understanding analogies, revealing patterns and projecting the results to large scale applications [28]. To this end, CT dimensions are evident to nanotechnology education activities. The applications of nanotechnology are very beneficial to society, ranging from smart materials to information and communication technology, energy technology, and medicines. This means that nanotechnology has already been embraced by many Industry 4.0 sectors.

Currently, there are plenty of learning and teaching materials related to CT, which propose activities to develop CT competencies, available in various formats [14]. These teaching materials are accessible by both STEM and non-STEM related instructors [12]. An example of this type of educational material is available in the project CS Unplugged [13], which explains how the concepts of CT (algorithmic thinking, abstraction, decomposition, generalization and patterns, logic, and evaluation) can be applied to each pedagogical activity.

Additionally, the development of emerging technologies, such as Virtual Reality (VR), Robotics, Augmented Reality (AR), etc. has led to the adoption of new didactic material and tools, such as STEM courses and experiments utilizing Arduino controllers [31] [33]. These materials require students' familiarization with Computer Science principles and Computational thinking skills in order to be utilized properly. A characteristic example is shown in [32] where the Arduino board is used in Primary education for teaching STEM following the problem-based learning (PBL) methodology.

Although in [14], [15], various approaches relate educational activities to CT skills cultivation, to the best of our knowledge, there are no similar materials, to encourage and support instructors in utilizing Nanotechnology withing their STEM (or non - STEM) training activities [7]. On the contrary, the majority of existing Nanotechnology learning material is mainly technical, focusing on Biomedical, Biology, Chemistry, Materials domains [20], [21]. There are very limited (or no) works on STEM activities with a focus on the correlation of understanding Nanotechnology, scales and applications, by engaging with CT activities.

To deal with the aforementioned gap, in this work, we investigate teacher's attitude towards integration of Nanotechnology activities, within STEM related and CT framework, as well as their willingness to follow appropriate training, in order to understand, design and produce innovative learning material and nanotechnology related activities. We also propose and acquire a free online learning platform, available to the teaching community, which works as a repository with ready 3D designs for Nano - structures, nano - sensors, along with ready lesson plans and STEM rubrics. Our main goal is to promote Nanotechnology, within this learning design framework, as a part of the problem solving STEM approach.

II. Research Methodology

A. Questionnaire

Surveys in Greece and Cyprus [6], [23], conducted for schooling education teachers, show that there is no consensus on whether Nanotechnology need to be included in the curriculum [21]. According to [24], the majority of learning curricula is related to technical domains for chemistry, nanomedicine, nanoelectronics, smart materials etc., but there is a gap for learning activities, introductory to nanotechnology applications and projections among nano and macro scales. As there is no (or very limited) investigation about the importance of teaching Nanotechnology basic ideas and its correlation with CT skills as *problem-solving, decomposition, and abstraction (CT concepts)*, we aim to provide a learning framework to close this gap.

In [7], authors underline the necessity for research community to propose and promote ways to contribute to a comprehensive curricula for teaching Nanotechnology in high schools and higher education. The lack of properly designed, STEM - based and practical hands - on material, may cause teachers to become averse to teaching Nanotechnology's background concepts.

In [25], we design and use a five scale Likert survey questionnaire, based on the following categories (C):

C1 Teachers' beliefs and perceptions of Nanotechnology in education ([Q1], [Q2], [Q3])
C2 Teachers' beliefs and perceptions about the relationship between Nanotechnology and Computational Thinking skills development ([Q4], [Q5], [Q6])
C3 Teachers' beliefs and perceptions about career perspectives in the Nanotechnology field ([Q7], [Q8], [Q9])
C4 Teachers' beliefs and perceptions about the existing teaching material concerning Nano literacy ([Q10], [Q11], [Q12])

The questionnaire is anonymous and the target is STEM and non - STEM related teachers, instructors and professors, which are informed by a promo video. This video explains what is Nanotechnology, which skills are related to this scientific field and why is it worth including to new curricula, to support the skills for Industry 4.0 application. The questionnaire has two parts. In the 1st part, we collect demographic information, regarding participants' field area, years of working experience and their education level. In the 2nd part, the survey focuses on questions related to the aforementioned categories. In Table I, we give all questions per category.

B. Proposed Learning Framework and Repository

Apart from investigating the teachers' attitude towards the significance and potential inclusion of Nanotechnology activities in innovative STEM curricula, we envision and propose a learning framework, based on the *Engineering Design Process (EDP)* [29]. EDP is a systematic and iterative approach, used by engineers, to solve problems and develop new products and systems. It is a contemporary teaching method, appropriate to implement STEM education scenarios [30]. According to Fig. 2, it involves a series of eight steps, that guides students (i.e. working as *engineers*), from identifying a problem, to creating a prototype and implementing a solution for a specific STEM problem. EDP process, is not always conducted in a strictly linear and circular way, and students may revisit earlier steps, gather more information, giving feedback to the prototype or encounter new challenges along the way.

In Fig. 1, the System Model for *RPNT* Repository Platform for Nanotechnology is shown. In essence, RPNT interacts with both students and instructors, collects and categorizes all necessary 3D designs and didactic plans gives advice and constructs rubrics, according to the learning objectives. Students may upload and download 3D designs (i.e. .STL, .OBJ, .SVG) files, mainly designed in *TinkerCAD*, as shown in Fig. 3 Teachers also interact with RPNT by uploading and downloading lesson plans, activities and 3D design files. The

TABLE I: Research Questions

	Questions
Q1	Nanotechnology is an important tool for understanding STEM
Q2	Nanotechnology should be taught in compulsory education
Q3	Teaching Nanotechnology orients students to new research and technology opportunities and helps them enhance their ambitions
Q4	Nanotechnology has contributed greatly to fixing problems in the world
Q5	Nanotechnology develops evaluation skill (Embedded Digital Twin)
Q6	Nanotechnology prompts both teachers and students to better model a problem
Q7	I can easily participate in a discussion for Nanotechnology
Q8	I'm certified in teaching Nanotechnology
Q9	I understand the career opportunities in nanotechnology
Q10	I can easily find useful teaching Nanotechnology material on the web
Q11	I am familiar with the usage of Nanotechnology teaching material in the classroom
Q12	I need didactic material for boosting CT concepts through Nanotechnology teaching

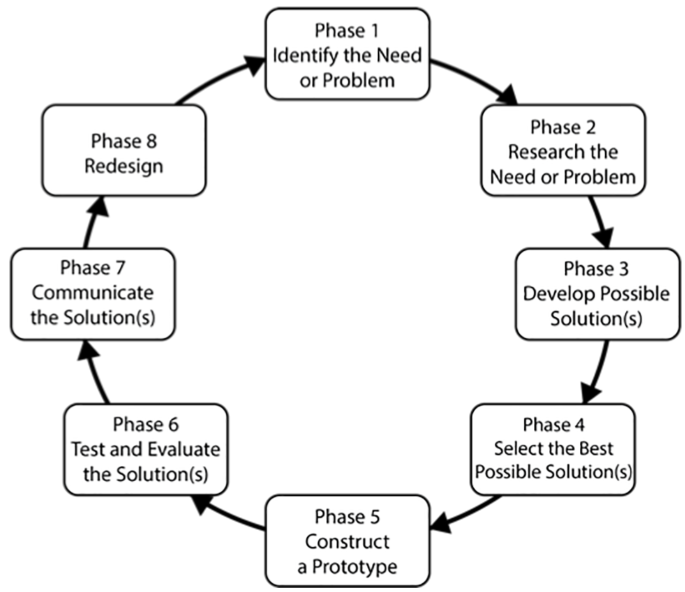


Fig. 2: Phases of the Engineering Design Process (EDS)

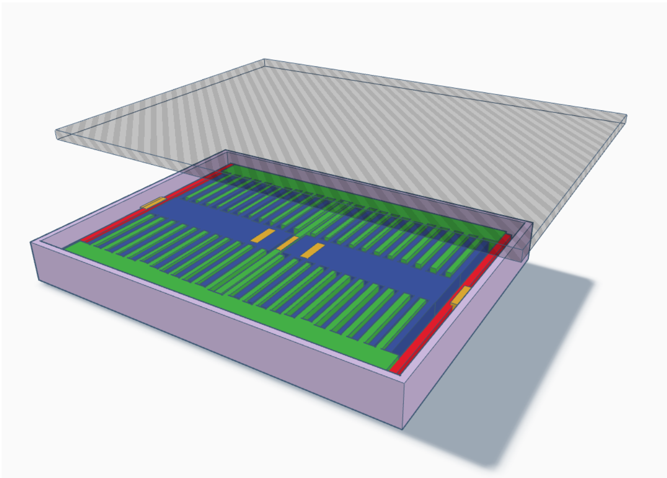


Fig. 3: Dual-Axis Accelerometer design in TinkerCAD

heart of RPNT is an expert system, which produces as an output, assessment rubrics, according to the input learning objectives.

Focusing on the technical characteristics of RPNT, the educational material relates to:

1) 3D designs of Micro-Electro-Mechanical Systems (MEMS) such as:
   - Accelerometers
   - Gyroscopes
   - Humidity sensors
   - Temperature sensors
   - 3D accelerometer and 3D magnetometer
   - MEM Microphone
2) Lesson plans and tutorials
3) Course evaluation rubrics

The repository platform is built on WordPress 6.3.2, with MariaDB as the database, while the lesson plans are constructed according to WordPress Tutor LMS and each lesson material also relates to a video course, along with quizzes, with h5p.org Web 2.0 tools.

III. Results and Discussion

The anonymous study, is conducted during September 2023, and includes N = 48 answers from STEM and non - STEM related teachers (i.e. instructors). Their distribution, according their scientific field, working experience and education level, is the following:

- *Scientific field:* 39 teach STEM related course (i.e. Maths, Science, Computers, Engineering and 9 teach non - STEM courses, according to TableII
- *Working experience*: 10 with 1 - 5 year, 17 with 6 - 15 years, 7 with 16 - 25 years and 17 with 26 - 35 years, according to Table III
- *Education level*: 8 with a Bachelor degree, 25 with Master's, 8 with a PhD and 7 with a PostDoc experience

TABLE II: Scientific field Distribution

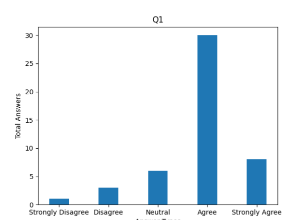
Levels	Answers	Total %	Cumulative %
STEM (Technology/Engineer/Informatics)	39	81.3%	81.3%
non-STEM	9	18.8%	100.0%

TABLE III: Years Of Experience Frequencies

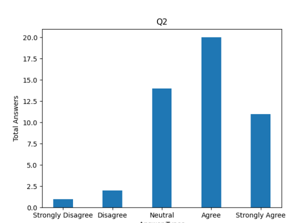
Years	Answers	Total %	Cumulative %
0 - 5	10	20.8%	20.8%
6 - 15	17	35.4%	56.3%
16 - 25	7	14.6%	70.8%
26+	14	29.2%	100.0%

The results, concerning descriptive statistical parameters such as *Median, Mode*, and *Min, Max*, according to questionnaire's Category 1 (C1), are shown in Table IV. Following, the answers frequencies, related to questions *Q1, Q2, Q3*, are shown in Fig. 4. We observe that the majority replies as *Agree* or *Strong Agree*. However, it is worth further analyzing how the answer to *Neutral* option, affects or not, the interpretation of the results.

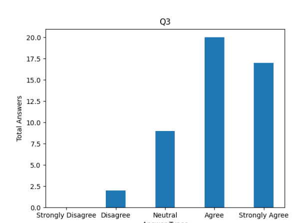
To do so, we apply the *Mann - Whitney U* test, also known as the *Wilcoxon rank-sum test*, which is a non - parametric statistical test, used to compare two independent groups, when the dependent variable is ordinal or continous, but not normally distributed. To this end, we investigate the differences in the rank distribution of the samples, between the *independent* variable *Scientific Field* of the answer samples. As long as value $p \geq 0.05$, there is no significant statistical difference, so the *Scientific field* does not affect the participants' answers. The *p - value* for questions Q1, Q2, Q3, as shown in V are



(a) Answers for Q1



(b) Answers for Q2



(c) Answers for Q3

Fig. 4: Answer Frequencies for Category 1 Questions

TABLE IV: Teachers' beliefs and perceptions of Nanotechnology in education

Descriptives						
	N	Missing	Median	Mode	Min	Max
Q1	48	0	4.00	4.00	1	5
Q2	48	0	4.00	4.00	1	5
Q3	48	0	4.00	4.00	2	5

TABLE V: Mann-Whitney U statistics for Scientific field

		Static	p
Q1	Mann-Whitney U	142	0.307
Q2	Mann-Whitney U	108	0.061
Q3	Mann-Whitney U	137	0.277

greater than 0.05

Following, in order to investigate differences in the rank - distribution of the samples for each question Q1,Q2,Q3, we examine the non - parametric *Kruskal - Wallis* test, between the independent variable *Education Level* of the sample and we find that there is not statistically significant difference, as according to *p - values* of V. This result states that *Education Level* did not affect the participants' answers.

In the sequel, in order to investigate differences in the rank - distribution of the samples (Rank) for questions Q1,Q2,Q3, we examine the non - parametric*Kruskal-Wallis test* between the independent variable *Working Experience*, and we find that there is no statistically significant difference, as *p - value* is greater than 0.05 in all cases, according to VII

Finally, for the results of *Wilcoxon by* H_a, $\mu \geq 3$ (neural), for Category 1 questions bundle (i.e. textitTeachers' beliefs and perceptions of Nanotechnology in education), we find that there is a statistically significant difference present to a positive attitude, towards Nanotechnology use in Education, as *p - value* indicates $p \leq 0.01$, according to VIII

Additionally, we perform similar statistical analysis for the remaining categories entitled: C2: *Teachers' beliefs and perceptions about the relationship between Nanotechnology and Computational Thinking skills development*, C3: *Teachers' beliefs and perceptions about career perspectives in the Nanotechnology field* and C4: *Teachers' beliefs and perceptions about the existing teaching material concerning Nano literacy*. According to the tests, regarding the parameters of *years of working experience* and *education level*, we find that there is a statistically significant positive attitude towards Nanotechnology to support Computational Thinking skills development and to contribute positively in career perspectives, related to Nanotechnology field.

TABLE VI: One-Way AOVA (Non-parametric) Kruskal-Wallis (Education Level)

	x^2	**df**	**p**
Q1	3.95	3	0.267
Q2	3.51	3	0.319
Q3	7.40	3	0.060

TABLE VII: One-Way AOVA (Non-parametric) Kruskal-Wallis (Working Experience)

	x^2	**df**	**p**
Q1	0.867	3	0.833
Q2	1.692	3	0.639
Q3	1.912	3	0.591

TABLE VIII: Test of Wilcoxo W

		Static	**p**
Q1	Wilcoxon W	814	<.001
Q2	Wilcoxon W	544	<.001
Q3	Wilcoxon W	757	<.001
Note. H_a μ >3			

IV. Conclusions

According to this work, the research emphasizes the need for teachers' support in teaching and preparing material for basic Nanotechnology concepts and principles, within the STEM framework. We statistically investigate instructors' attitude towards Nanotechnology applications and curricula enhancements and we observe that the majority supports the inclusion of MEMs technology to be included in their didactic materials. Additionally, we design and propose an innovative learning platform, with which teachers and students interact, exchange ideas, upload and download new material etc. In essence, the platform will work as a repository for material and good practices for Nanotechnology. Apart from their working experience and level of education, the majority of teachers believe that there is a necessity for the existence of such platform, which will improve the quality of education and make STEM lessons more attractive.

Moreover, the challenge posed by the proposed platform, is the inclusion and offering of learning activities, which boost CT skills and the evaluation of both teaching and learning outcomes by custom - based automated Nanotechnology skills - based rubrics.

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