

NANOSCIENCE AND NANOTECHNOLOGY AT HIGH SCHOOL: A HANDS ON, INQUIRY BASED APPROACH

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Inquiry based approach to Science is now discussed world wide as one of the keys to the development of pupils' renewed interest and effective teaching. However getting down to practice and comparing outcomes at different school levels, the upper secondary seems to display more resistance to implementation, with fewer examples of best practice; and a shared opinion of teachers that curricula requests and time constraints are impossible obstacles. In this presentation we will illustrate the experience in Modena (Italy) which brought together high school teachers and students, researchers and last but not least industry representatives. The focus is on Nanosciences and Nanotechnologies as an ideal playground to introduce cutting edge research topics and the basics of modern physics at high school in a hands on, inquiry based, intrinsically interdisciplinary modality based mostly on the study of new materials.

Key words: upper secondary, nanoscience, nanomaterials, modern physics, inquiry based

Introduction

At what point should one allow high school students to experience cutting edge science, such as Nanoscience ? When are pupils considered to have sufficient knowledge foundation for this in spite of the fact that they are daily exposed to and already massively consume the outcome technology? Generally speaking when it actually comes to experiencing science and not just learning it on books the sensation is that upper secondary doesn't score very high marks if compared to middle and primary school. This is a paradox since at this age kids should be more mature, more prepared, ready to make vocational choices ... Still teachers seem to take a step back! Some complain that teenagers lack in curiosity and that gets worse as they grow up. But the legitimate question is whether this is a failure in pupils or rather the effect of a less appealing Science Menu served.

The overall impression is that this is mostly a teachers' issue, due to a mixture of external constraints and personal beliefs. Among the first ones curriculum pressure surely is the top issue. Upper secondary teachers have also to face a higher level of abstraction and massive use of Math in doing science. That brings to a general shortage in time. Impending assessment and National tests play an important role too in discouraging IBSE practice since it doesn't seem to be found any reference to it and the acquired skills anywhere. Plus how to grade open inquiry work is still an open issue since new paradigms are called for and in any case it can't be denied that this is a time consuming task. Last but not least, and quite specific of the Italian context, there's the so called «scaffolding» curse. The historical approach settled decades ago still perpetuates itself and brings to the diffused practice of vertical approach rather than horizontal one in schools, which ultimately brings to the

introduction of almost no new topics at all! Lack of equipment and funds add a final touch to the discomforting picture.

Among personal beliefs a certain lack in confidence is recorded. Many teachers have little experimental experience in general and no personal experience at all in research. IBSE however definitively calls for a new teacher's role: no "sage on the stage" but "guide on the side", compelling in a not artificial way to focus more on experimental method and research skills than actual content transmission. Someone also objected that this methodology is only suitable for younger pupils not being able to be applied in complex contexts. To overcome such an opinion just link to the International Young Physicists' Tournament website <http://iypt.org>, a team-oriented scientific competition among secondary school students with a set of highly challenging but still very stimulating open ended inquiry based experimental problems to solve.

Nanolab Project



As it will appear clearly from this paper in NanoLab project (www.nanolab.unimore.it) great effort has been put in trying to address most of the above listed issues with the obvious exception of assessment.

The choice to focus on Nanoscience came primarily from the long standing tradition of the Physics Department in Modena in solid matter studies as a researchers' outreach attempt. But more important intrinsic reasons can be added. Many properties of matter (such as conductivity, colour, pliability) which can be appreciated at the macroscale even in a school lab, are actually determined at the nanoscale and can be sometimes envisaged as the effects of quantum physics at work. Nanosciences and nanotechnologies are therefore an ideal playground to introduce cutting edge research topics and the basics of modern physics at high school with a hands on and intrinsically interdisciplinary approach. Moreover they naturally link fundamental science both to actual technology and to feasible one: it's a fact that in spite of the falling interest in Physics and Science traditional curricula young students are nonetheless fascinated with the latest research and its technological outputs. Last but not least they enhance Inquiry Based Science (IBS) approach at secondary level. IBSE was not the first focus but it was immediately evident that it suited NanoLab project aims perfectly since it is based on students' active involvement, offers significant tasks linked to the real world and is a working style. Pupils learn to ask questions and use evidence from their own experimental work to answer, formulate conjectures, make predictions, communicate conclusions and get ready to further discuss them.

Among Nanolab Project main characteristics, researchers' involvement in designing and implementing experiments, counseling, developing didactical materials and supporting teachers' professional development rates first. But even more appealing to teachers will be the fact that great pain has been taken to make the experimental activities easy to perform also in school labs, short (1-2 lessons at most), low cost (reasonably cheap materials and equipment are needed), with a strong interdisciplinary approach (involving Physics, Chemistry, Biology), easy to tailor to suit different

needs and levels ranging from simple demonstrations to guided experiments and open inquiry activities.

In the attempt to pursue cheap solutions without losing in sophistication and efficacy a massive use of new technology tools, some of them already owned by students such as cameras, iPhones, cells, has been fostered.

With regard to topics choice, all are highlighting fundamental points in nanoscience such as the fact that at the nanoscale new properties can be observed and new laws are dominating; atomic manipulation can bring to new pre-designed materials and to this aim new tools are needed.

Although addressing nanoscience the activities still teach fundamentals and strongly link to curricula supplementing traditional topics. In fact nanosciences and nanotechnologies rather than a self-standing module were introduced since the first stages as a “*fil rouge*” across the curricula, integrating interdisciplinary research and technology with traditional science concepts sometimes challenging “school linear physics”. This also helps in saving time and finding an appropriate slot for the nano activities.

Topic	Key idea	Link to curriculum
Memory shape alloys	properties are determined at the nanoscale : atomic manipulation for smart materials	phase transition, metals behaviour on heating ...
Gold Nanoparticles	size matters; light and matter interaction	light scattering, spectrometry, particle diffusion
Nanostructured Surfaces	new hierarchy in forces	Forces, friction
Conductive polymers QTC	Quantum Physics at work	conductivity

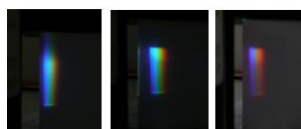
Table 1 – NanoLab contents and their link to the curricula

Just to have a quick overview of the topics addressed so far and the physics and science they involve we will give a few hints inviting all interested ones to refer to the website for further detail.



Memory shape alloys allow for introducing the concept of “smart materials”, which is actually central to nanotechnology, and the idea that changes at the atomic scale deeply influence the macroscopic properties which ultimately can be used to monitor nanoscale modifications even without highly sophisticated equipment. At the same time students are brought to revise and further investigate curriculum traditional topics such as phase transition, metal behavior on temperature change, acoustic transmission, electrical resistivity, efficiency. Still keeping the «wow factor» as a motivating input the activities upgrade from simple demonstrations to real quantitative and sometimes even quite complex experiments. To appreciate the very fast movements of the shrinking nitinol, video recording is exploited, together with subsequent video analysis. Both modalities reach a quite detailed level of data acquisition and reveal themselves as high precision lab tools allowing measurements impossible by hand only, saving time and offering a relatively high precision at almost zero cost. Videos can be taken in fact also with

students' mobiles and the software for video analysis is a free one Tracker [1]. For well equipped schools the use of online acquisition with sensors is highly suggested but not a must.



Gold Nanoparticles activities easily demonstrate that size matters and allow for further delving into the study of light and matter interaction and the physics of colour. A demonstration of the gold colloid use in medicine as plasmonic colorimetric sensor (the change in hue is a direct signal of the aggregation level and particles dimension) leads the way to the introduction of spectrophotometry principles and their classroom practice with off the shelf equipment [2]. However since as in real research not everything can be dealt with experimentally, a didactical simulation is available to pursue the subject further by parameters manipulation. This is IBSE too although practiced with virtual tools rather than real lab ones! Another medical application, namely the use of gold nanoparticles as drug carriers for targeted release in cancer therapy, together with the major concern of nanoparticles possible effects on the human body upon absorption call for the study of a diffusion model.



Nanostructured surfaces lend themselves to spectacular demonstrations such as Gecko and Lotus effect. Bio-inspired manipulation at molecular and atomic level can in fact lead to the design and synthesis of new materials with new functionalities such as super adhesives or super hydro phobic surfaces. But there definitely is more than meets the eye : contact angle; adhesion; capillarity; superhydrophobics, superhydrophilics and amphiphilic molecules; nanolithography; microfluidics; hierarchically nanostructured surfaces; physics of droplets; inks for printable electronics are just some of the topics that can be linked and addressed. But a particularly poignant aspect relates to nanoworld forces and a totally new hierarchy from the one we are accustomed to in the macro world. At the nanoscale gravity effects can often be overlooked; electromagnetic and intermolecular forces play a dominant role **owing** to the very small masses and large surface exposure. Most of the atoms and molecules at this scale are in fact at the interface thus surface properties in objects are dominated by **surface interactions**. Tribology, a current curricular topic has to do with interfaces and it will be shown that nanotribology is not just a proportional scaling down of macro friction.



Conductive polymers naturally link to the curricular topic of electricity and charge transport, enriching the isolant to conductors spectrum revolutionized by the most recent technologies mainly regarding printed electronics. A particular material QTC [3] has been chosen for thorough investigation owing to its quantum tunneling based conduction mechanism. Starting from the reflection on what are the characteristics of a good sensor and ultimately of lab tools in

general, pupils are further led to obtain the exponential model of resistance versus pressure response in QTC and to plot the IV curve whose completely new and never observed before shape naturally calls for discussion and new interpretation.

Nanomaterials A central role in the project is played by nano materials. Students are excited to deal with the real “stuff “! Produced with specific and predesigned physical and chemical



properties, nanomaterials are actually leading to many and appealing applications from energy harvesting to space flight. Many of them have only recently been designed and most of their applications are still in the development stage. This means that students are able to use them in schools sometimes even before they have found their way in many commercial products which is in

itself already quite motivating. In some cases the materials behavior is not yet fully understood and the investigation that students can perform really reflects the kind of research that is now being done in laboratories around the world. This is a great way to complement and sometimes even challenge pupils' "school" Physics knowledge, compelling them to refine their design and experimental skills directly "on the field": predicting, designing and implementing new experiments, collecting and interpreting data, looking for more to support such interpretations, visualizing new possible applications.

Another aspect of these quite new materials is that since they are **unknown**, no preconceptions are formed, both students and teachers cannot appeal to text-book 'truth' and results can't be faked to make things right according to the manual! This naturally brings to focus more on methodology than actual results and makes a perfect scenario for IBSE. Most of the used samples are quite cheap but not ordinary or easily accessible on the educational market : collaboration of firms and research centers is thus essential . Minimum order quantity could actually be an issue for schools too.



Teachers' training and support

As stated at the beginning, teachers' training is a most crucial issue and the only way to tunnel through to students. A first professional development course was held in Autumn 2011 in Modena and more are planned for the future. Thirty teachers were selected out

of the 54 requests coming from all over Northern Italy. According to their declarations most of them didn't routinely introduce research topics and modern Physics in their lessons; 60% often brought classes in the labs BUT no one with open inquiry modality. At the end of the course 74% declared they would implement at least one of NanoLab activities within their classes within the same school year or in the next coming one.

To support teachers in experimenting further with their classes since most of the materials used in the experiments although quite cheap are not ordinary and easily accessible, particularly with regard to nano materials samples, there's also a plan to implement a toolbox with consumables.

However the number of teachers that can be directly addressed with courses is a minority. To reach a wider audience and disseminate the project website (www.nanolab.unimore.it) offers free download of materials and resources, most of them editable under the Creative Commons not commercial share alike License. Each activity comes with background reading, correlated seminars

held by researchers , students' editable lab sheets , editable PPT and the teachers' guide with didactical notes and practical ones (building instructions, prices and addresses for buying samples and equipment) complemented by laboratory video guides which actually are of the main importance for distance training. At the moment the website is mainly in Italian but an English version is under construction too.

Notes

[1] Tracker video analysis software. <http://www.cabrillo.edu/~dbrown/tracker/>

[2] Alexander Scheeline, Kathleen Kelly
http://www.asdlib.org/onlineArticles/elabware/Scheeline_Kelly_Spectrophotometer/index.html

[3] QTC is a product by www.peratech.com