SCIENTIFIC METHOD CANVAS TO FOSTER SCIENTIFIC THINKING AND STEM VOCATIONS THROUGH VISUAL THINKING STRATEGIES

Carlos Bravo-Díaz1, Sonia Losada-Barreiro1, Cristina Bravo-Fernández2, Carolina Fernández-Bravo3

1Dpt. Química Física, Fac. Química, Universidad de Vigo (SPAIN)
2IES Carballo Calero (SPAIN)
3Centro Formación Profesorado (SPAIN)

Abstract

Visual Thinking (VT) is concerned with the use of visual resources (diagrams, simple drawings, short texts) to represent, organize or communicate ideas or contents. VT aims to favor the understanding of concepts by "translate" to a visual representation a content or process. Lower thinking skills to remember and understand concepts are necessary as much as higher order skills to filter, manage and spatially organize contents. VT offers us a slower, but more effective, way to learn and teachers are increasingly using VT for educational purposes in their lectures.

Within the VT techniques, we have set ourselves in the so-called canvas as a template that allows to visually structuring the fundamental elements of an entity or process. As an example of use in the educational field, the PBL canvas proposed by conecta13, describes a Project Based Learning process in nine steps (key competences, learning standards, evaluation method, final product, tasks, resources, ICT tools, grouping and organization and dissemination).

On the other hand, we find the need to encourage Science, Technology, Engineering and Mathematics (STEM) vocations, especially in women, given the decreasing interest in these areas (Science, Mathematics, Engineering and Mathematics) considered more arid and boring by students. This makes us to face a paradoxical crossroad, since much of the jobs of the future will be linked to these fields. It is therefore necessary to bring the methodology of scientific thinking closer to the students by presenting it in accessible ways.

Here we propose a canvas that provides a visual structure to represent graphically the various steps of the scientific method. These steps include the systematic observation, formulation of hypothesis, design of the experiment to prove or discard them, to finally elaborate some conclusions leading to development of a theory. The canvas is used as a visual tool to support the design to summarize the results of the scientific experiment, to cover the different steps in a schematic way either with text or graphically. An empty template is provided as well as different examples of the canvas covered with experiments that can be carried out in different pre-university educational levels. In order to let this canvas become part of the public domain it is released under the Creative Commons Attribution-Share Alike license, so that anyone can use it, copy or modify by free, with the only condition of attributing the corresponding authorship and keeping the license open.

Keywords: Visual Thinking, Canvas, STEM vocations, Scientific Method, Creative Commons, Experiences in education, STEM in education.

1 INTRODUCTION

The "society of knowledge" towards we are heading in convergence with our European neighbours and the rest of the developed countries implies a significant increase in the percentage of jobs related to the stem areas. Being one of the main goals of national educational system the preparation of young people for their integration in the societies of the future, it seems appropriate to consider how to improve the way it is been taught Science, Maths and Technology as well as try to find ways of empower future stem vocations.

The second part of the study released by the University Camilo José Cela (UCJC, Madrid, Spain) shedding some light on PISA 2015 results at the end of 2018, entitled "La educación científica en las comunidades autónomas", includes some specific recommendations to improve the poor results on Science performance and the scarcity of STEM vocations such as:
• Promoting the presence of scientific fairs and competitions and facilitating participation in both teachers and students on Science and Technology related forums.

• Including on Science subject curriculums objectives aligned with epistemological aspects of scientific knowledge.

• Organizing learning situations around laboratory practice or virtual simulations that familiarizes students with the practical implementation of scientific method.

• Designing experiments that challenge preconceptions based on common sense that can be empirically refuted.

• Using reports as exercises of simulation of scientific activity analogy, on their level, to the drafting of scientific works that could be published on scientific publications.

• Resorting on "project-based learning" in the understanding that broader integrated learning should be combined with direct instruction.

• Promoting “deep learning” characterized by high level of understanding of phenomena, of the conceptual a theoretical foundation, cause-effect mechanisms, it meaning and transferability. This deep knowledge facilitates de consolidation of those metacognitive skills that PISA study call "epistemic convictions".

The study has also points out a worryingly gender gap on Science, Technology, Engineering and Mathematics (STEM) vocations, where only 4.2% of 15 years old girls consider pursuing an STEM career. The absence of female presence on STEM jobs has started to be addressed with specific programs of mentoring starting on young age such as primary school, going up to secondary and university level. And as a further step, it is also provides to many organizations, such as the “ASOCIACION DE MUJERES INVESTIGADORAS TECNOLOGAS” (AMIT), opportunities of working for the empowering, recognition and visibility of women in Science and Technology.

In latest years, most of educational systems of developed countries are adapting their curricula towards a competence based model [2]. This approach claims the crucial importance of applying knowledge for creative and genuine decision making as the only way to understand and transform reality, as opposed to machine’s way of behave, only been able to perform repetitive tasks and limited reasoning. Curricular design, development and assessment is been oriented to merge a set of resources (previous knowledge, know-how, observation, capacity of analysis and synthesis, critical thinking, social and communication skills) toward solving a given situation or problem.

Related to this, John Dewey’s “learning by doing”[3] methodology goes beyond the traditional saying that affirm that procedural ability needs to be put into practice in order to be fully incorporated in our mind-set and suggests that all learning should be directed towards applied knowledge keeping in mind the need of putting it into practice from the very beginning, as the main goal pursued that make worth acquiring a piece of knowledge. We also can interpret this quote as the fact that conditioning a space where arts and crafts are developed mixed with new technologies such as 3D printing, laser cutting, electronics, etc., conveniently planted with the seeds of curiosity and scientific inquires, creating an atmosphere where the culture of knowledge has all chances to flourish.

Martinez and Stager [5], based on the work of Seymour Papert (predecessor of maker movement and convinced defender of Constructionism) gave their own twist to the previous concept with their “Invent to Learn” putting at the centre of learning the creative process making an staunch defence of constructivism that may not leave much room for the need for observation, analysis and interpretation of reality often required by science.

On this context, Project Based Learning is pointed out as the best tool for teachers to structure lessons in many cases, and particularly in what refers to experimental sciences. This strategy presents many advantages in relation to traditional master classes such as: 1) Goal orientation 2) Interest and motivation boost 3) Clear and limited duration. 4) Independent learning development 5) Critical thinking enforcement 6) 3) Real live connection. Rubrics of evaluation has appeared as an evaluation method that adapts naturally to this type of tasks. Besides, gamification techniques such as badges, points or rankings have proven successful on reinforcing certain aspects of learning by boosting healthy competition between classmates.
2 METHODOLOGY

Before designing a learning material to act as a template for experiment based projects, lessons or lab experiences, is necessary to talk about what is understood for scientific method as the standard work scheme used by scientists for centuries.

The scientific method is a logical way for scientists to study aspects or phenomena of the reality and come to conclusions that will become the foundations of known pieces of knowledge; confirm hypothesis based on empirical data retrieved from tailor-made experiments. Regardless of what it is being tried to be proved, the use of the scientific method can help to guide and structure the process to maximize the chances of drawing accurate conclusions.

The very first thing to do is to clarify the question that is being tried to be answered. After all, it does not seem too sensible to try to find an answer until the question is clear and fully understood. The next step is to formulate a guess or a hypothesis taking into account the observations and information gathered till the date. Then, experiments are conducted to prove or discard the hypothesis or to provide new ones. Even, on the basis of the exiting information, it is possible to reformulate the previous hypothesis. A good strategy when conducting experiments is just changing one variable at a time. In this manner, it is possible to contrast the results obtained assessing if the changes are in keeping with the formulated hypothesis. After running a pool of test, is possible to present the final conclusions and eventually formulate theories.

Repetition of this process brings scientists a universal method to verify their conjectures and to contrast the work of their peers. i.e., other scientists can take a look at your tests and experiments, and add some more tests, continuing to refine, enlarge or broaden the given answer to the question. The scientific method is one of the cornerstones of modern science. Without a formal method of guiding the process of formulating question, performing tests, collecting results and elaborating conclusions, science would not have evolved to the high levels of sophistication that it has achieved today.

It is important to notice that the scientific method has not been invented by only one individual, but has been developed by different scientists and philosophers over the centuries. Among many others Francis Bacon, Rene Descartes, and Isaac Newton have contributed to the development of the scientific method as the best way to learn about the reality we live in. There is still no little scientific literature written about disagreements on exactly the best way to implement it.

Taking into account all those considerations, the proposed steps to represent the phases of the scientific method, in an attempt to summarize and simplify the process as much as possible, are the following:

1 Observation of a phenomena and set the query that will guide the process.
2 Research (gather information and observe)
3 Hypothesis (make reasonable assumptions to explain the observations)
4 Experiments (run different tests trying to verify your hypothesis)
5 Results (analyze the collected data).
6 Conclusion (summarizes and interprets the obtained results). Those steps have been used to design the sections of the canvas and will be represented as separated boxes in order to make easier visualizing the structure of the full process.

The proposed canvas template has been released under license Creative Common BY-NC-SA 2.0 [5]. These license grant permission to the interested user to use, share and adapt the canvas as far as the aim of the authors by doing this is to provide the entire educational community with a tool to facilitate author is properly credited, the same license is preserved and no commercial benefit is pursued. The project-based learning within the STEM field making a special emphasis on the scientific aspect of it with the intention that students start assimilating, in the easiest and most intuitive way possible, the rigor and “know-how” of the scientific method.

This strategy is aligned with the Open Access concept, the practice of providing on-line access to scientific information that is free of charge to the user and that is re-usable, recommended by ‘Digital Single Market’ Strategy [6] of Horizon 2020 work program.[7] And more generally, it reflects the conviction that Open Culture is an engine of research and innovation advanced societies, and is an step forward on the pursuit of excellence in education. Is worth to mention the case many renowned
European scientists such as Alexander Fleming or Marie Curie who shared their work with the public domain and understood science as a way of life focused on discoveries that could improve the quality of life of the human being instead of a way of economic enrichment.

3 CASE STUDY

Figure 1 shows the proposed canvas for been used as kind of form to fill during preparation and implementation of experiments during stem lessons. Is freely accessible online and is planned that it will be soon available on eight different languages English, Finish, French, German, Greek, Italian, Portuguese, Spanish.

![Figure 1. Scientific method Canvas on its version 1.0.](image)

Figure 2 shows an example of usage of the canvas gathering all the information about the experiment “floatability test” made by and fourteen years old student.
4 CONCLUSIONS

There is an urgent need to find ways of developing students’ confidence and competence on independently designing and conducting experiments and observing and interpreting result even if no apparent relevant findings are revealed. To truly become the protagonist of their own learning by setting their own goals and managing the process until reaching a conclusion that can be unexpected and to be in contradiction with the initial premises. Observe the reality, collect data and draw conclusions from its interpretation. Teaching children the scientific method by empowering their critical thinking and independent behaviour as individuals inculcating the culture of learning is handing them the key of evolution and of our future.

The Maker movements that it has been introduced on our educational system in the different regions of Spain promoted by educative administration following European Union guidelines provide scientist with an unforeseen powerful toolbox opening the door to the possibility of designing custom made tools for every experiment that can fit the exact needs in each case.

It is important that science leads the future of the maker spaces, that could otherwise become mere craft workshops or eccentric inventions, to focus on useful objectives focused on enrich and enlarge human knowledge and improve the quality of life of the human being.

The need to convey the certainty that the rigorous, patient but also ambitious execution of the scientific method will lead us to reach goals and make possible advances based on highly complex reasoning that would otherwise be unfeasible.

The canvas method has been proved a useful educational tool for STEM subjects; particularly to the Core “Science” subjects Chemistry, Physics and Biology and its usage can be extended to STEM projects giving a more.

It also helps to work on improving communication skills to describe facts, perform test and record data as it forces the need of summarizing information in a short space requiring choosing only the most important aspects to be written down.
This canvas can be a good starting point for students who have showed difficulties to put in relation theoretical concepts with daily live facts, poor communication skills, poor practical reasoning ability and poor independent learning skills.

ACKNOWLEDGEMENTS

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REFERENCES


[5] https://creativecommons.org/licenses/by-nc-sa/3.0/es/


[8] https://github.com/carolinafbravo/scientific-canvas