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Control Engineering and Mathematics: a new hands-on pedagogical approach through the perspective of Art [★]

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Abstract: This paper proposes new popularizing science activities based on artistic concepts, promoting diversity and inclusion among secondary and high-school learners. Two easily reproducible workshops are designed to arouse girls' interest in Science, Technology, Engineering, and Mathematics through the Arts perspective. Therefore, basic scientific concepts in Mathematics and Automatic Control are proposed for young participants from the artistic standpoint of Architecture and Animation, respectively. The Maths workshop focuses on fractals and golden ratio, while the Control workshop explains the feedback-loop elements. A video containing the first Control Engineering animated cartoon explains basic concepts of Control in an artistic manner, highlighting the importance of the controller, actuator, and sensor, illustrated on a drone. Lessons learned and feedback from the workshops participants are discussed.

Keywords: Control Education, Systems and Control for societal impact, Young Engineers in Control, Developments and opportunities in education, Digital diversity and inclusion, Control, automation and intelligence for sustainable cultural heritage.

1. INTRODUCTION

In recent years, diversity and inclusion aspects are increasingly addressed in engineering to foster creativity and innovation, to enhance engagement, to propose more effective solutions, etc. Therefore, recruiting more girls in engineering is a key objective of numerous universities in Science, Technology, Engineering, and Mathematics (STEM). Within this line, an idea consists in arousing the interest and commitment of a young audience, from middle-school to high-school learners, while seeking to reduce gender inequalities, particularly in the scientific environment, which numerous girls often tend to abandon, for the benefit of artistic studies. This motivates the need to establish new connections between Art and Science through funny and engaging educational workshops for kids.

Numerous practices allowing to bridge the gap between Arts and Engineering relies on proposing interdisciplinary projects at school and developing educational programs that combine Arts and STEM. Several engineering universities proposed new curricula with a selection of courses

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dedicated to Art. For instance, the paper Dahle et al. (2017) reports the possibility to combine a Major in Engineering (e.g., Mechanical Engineering, Electrical Engineering) with a Minor in Art, among “Art Studio” and “Digital Design and Fabrication”, addressing courses like “Design Color”, “Sculpture”, “Introduction to Computational Media”. Proposing engineering elective courses combining art with engineering was implemented at University of Toronto, as detailed in Tallman (2013), to bridge the boundaries between artists and engineers. As detailed in Murzi et al. (2022), an interesting study has been conducted in the United States to analyse the first-year engineering students' perception about engineering through drawings. In France, CentraleSupélec has a rewarding program called “CentraleSupélec talent” which recognizes its engineering students with outstanding achievements during their studies in a cultural, artistic, social, academic field, sport, etc. The Virtual Festival “WÆ – womxn from arts to engineering” organized by German researchers allowed worldwide participants to exchange on topics covering Engineering and Art, e.g., artistic consensus for mobile robots as part of Control Education framework Stoica Maniu and Bertrand (2022). In addition, new pedagogical approaches make Control Education more accessible both for engineering students (e.g., escape game for Control

Axelsson-Fisk et al. (2022), hand-on laboratories Takács et al. (2023), Ann et al. (2014), Petit-Magat et al. (2023), Stoica Maniu et al. (2020)) and for children (e.g., Girls in Control international workshop Knorn et al. (2021), DroPong game Bertrand et al. (2024)). Moreover, *static cartoons* (comic strips) on engineering themes are published in the IFAC bimonthly Newsletter Douglas (2022) and the IEEE WIE Manga Stories Sher-DeCusatis (2023).

In this context, the current paper proposes two innovative easily reproducible workshops using Arts for teaching basic mathematical and Control Engineering concepts to secondary school pupils, as detailed below.

- The first workshop innovatively combines fractals with concepts from *Architecture* (as Art) to raise middle school learners' awareness of a form of artistic teaching of *Mathematics*. By encouraging curiosity and exploration of diverse scientific fields through Arts, this project contributes to a more inclusive and balanced education in secondary schools.
- A second workshop consists of developing educational material for teaching basic notions of *Automatic Control* through the perspective of *Animation* (as Art). An essential contribution of this paper resides in creating the *first animated cartoon on Control Engineering* (to the best of the authors' knowledge) by traditional hand-drawn animation. The proposed video, inspired by Fontanive et al. (2014), aims to increase the general public's interest in Control Engineering and serves as a playful introduction to a formal undergraduate course. Using a visually appealing and educational format provided by the animations, the video facilitates understanding the elements of a block-diagram, while expanding the educational impact beyond traditional classrooms.

Quantitative feedback from the workshop participants carried out by a statistical analysis of the survey distributed at the end of first workshop is also proposed in this paper.

A *learning by teaching* approach is another important element of this paper. Indeed, these workshops have been designed and taught by a group of four undergraduate students of CentraleSupélec, during their first and second year project within the Projects Cluster "Pôle Projets Innovations Pédagogiques et EdTech".

The remaining part of this paper is structured as follows. Section 2 describes a first workshop combining Mathematics and Architecture, dedicated to the fractals basic understanding through the perspective of the golden ratio. Then, Section 3 focuses on a second workshop aiming at introducing Automatic Control concepts from an artistic point of view consisting in an animation video. An analysis of the workshops occurrence is performed in Section 4, together with lessons learned. Concluding remarks and further perspectives are provided in Section 5.

2. WORKSHOP ON "ART & ENGINEERING – FRACTALS AND GOLDEN RATIO"

This section focuses on the first workshop description and its timeline, to ensure its repeatability by a different teaching team/person.

This 90-minute workshop was designed to persuade teenagers to make connections between Mathematics (as scientific domain) and Architecture (as artistic domain). The *target population* is a group of 20 to 30 persons about 13 to 15 years old. The classroom has to be equipped with a computer and a video-projector.

The workshop was divided into a preamble and four main parts described below.

The **preamble** (approx. 10min) aimed to introduce the fractal concept from a purely visual perspective. Concise and emblematic slides prepared by the CentraleSupélec students illustrate common fractal images like Mandelbrot's set or magnified snowflakes.

Then, during an individual reflection phase, the participants take a few minutes to think how they could create a fractal. Next, during a class interaction phase, the discussions make the notion of *algorithm* emerge. This notion is further detailed in a simplified approach useful for the creation of fractals on computers. Thus, the concept of algorithm is drastically reduced to the single case of an iterative finite loop written in pseudo-code. An applied example on one of the teaching member trying to avoid collisions (as a vacuum-robot would do) is next carried out with the learners to consolidate their grasp of this new concept.

The **first part** (approx. 20min) of the workshop is dedicated to the hands-on session. The participants have to create their own fractal on paper and to detail each iteration step. This allows the teaching team to verify if the algorithmic process of the fractal creation is properly understood. To create a commitment feeling for the session, the classroom is divided in several teams of approx. four participants who compete for the best proposed fractal. After 15 min, one representative of each group has to present their team work to the classroom to obtain as many votes as possible from the other groups. The group with the largest number of votes is rewarded at the end of the exercise (e.g., they get a small gift prepared in advanced such as a printed version of a complicated fractal). The teaching team can highlight the algorithm construction steps to the classroom, and, when necessary, correct the presented results.

During the **second part** (approx. 10min) of the workshop, the golden ratio is introduced throughout the renowned construction of the "golden spiral". Indeed, since the spiral construction can be deduced from a geometrical algorithm tracing a fractal figure, this provides to the participants a clear link between their former fractal production and this other type of geometrical algorithm. With visual considerations, the learners are encouraged to formulate the geometrical equation to find the golden ratio, i.e.,

$$\phi^2 = \phi + 1. \quad (1)$$

The link with the art is shortly addressed in the this session by finding with the participants some "golden rectangles" hidden in well-known artworks where the author explicitly mentioned their use.

The **third part** (approx. 20min) of the workshop is designed to widen the scope of the golden ratio applications by introducing the notion of *sequence*. The well-known

example of the *Fibonacci rabbit problem* is next considered as a fundamental basis to provide a grasp of the former concept of sequence, together with the notion of *convergence*. The problem can be formulated in the following way.

(P1) “Consider a couple of young rabbits (*month 1*). The next month (*month 2*), the couple is old enough to give birth to a pair of bunnies the month after (*month 3*). According to your understanding of the process, what will be the number of pairs of rabbits in the following months?”

The idea is to encourage participants to find the formulation of the Fibonacci sequence which can be written explicitly as follows

$$u_0 = 0, \quad u_1 = 1, \quad u_n = u_{n-1} + u_{n-2}, \quad \forall n \geq 2. \quad (2)$$

The contextualization through the perspective of rabbits’ reproduction allows children to deduce the mathematical expression governing the number of rabbits’ pairs in function of time. The considered sample time is one month since this is realistic for the rabbits’ reproduction. Learners’ attention has to be brought on the ratio between two consecutive numbers of the Fibonacci sequence, to let them realize that these ratios “converge” to the correct value of the golden ratio. The notion of “limit” is not explicitly addressed to preserve the accessibility of the proposed approach. In the end, the learners are able to deduce (with no proof though) the well-known result

$$\lim_{n \rightarrow +\infty} \frac{u_{n+1}}{u_n} = \phi. \quad (3)$$

The **last part** (approx. 20min) of the workshop highlights the link between artistic expression and all the mathematical concepts described above by focusing on the French architect Le Corbusier (e.g., Butruille (2014)). Indeed, he is renowned for using the golden ratio in modern architecture under the name of “modulor”. Different structures designed by this architect using the golden ratio (e.g., Jaoul houses, Chandigarh city planning, La Tourette convent) are presented to the classroom. A particular attention is paid on St. Martin shed since it features the most explicit use of golden ratio in its design, before concluding the workshop.

3. WORKSHOP ON “ART & ENGINEERING – AUTOMATIC CONTROL AND ANIMATION”

This section details the content of a second workshop combining Automatic Control and animated cartoons. A first video from a series of animated Control cartoons is designed to illustrate the basics of Control. This video is aimed for secondary school and high-school pupils, and can be also watched outside the framework of a workshop. The engineering concepts are presented in a simplified manner and are meant to be accessible and inspiring, with increasing difficulty, providing continuity of the considered scientific concepts.

The first video (see Fig. 1), available on the YouTube channel of Laboratoire des Signaux et Systèmes (L2S) <https://youtu.be/BlwebsJofdQ>, is divided in *two sequences*.

The **first sequence** has several scenes, as details below.

- (1) The video starts with a key character who tells a funny story to the audience. The animated character presents the different components of a controlled system using an analogy with a painter. This analogy avoids starting the video by presenting a real engineering system, which could be complex or too similar to a traditional Automatic Control lecture and could lose its popularizing science flavour. Notice that a boy is designed for the moment in order to match the recorded voice-over. In future extensions of the video, a girl is also envisaged as main character.
- (2) The role of the *controller*, *actuator*, and *sensor* and the way they interact with each other are explained through a fictitious system that would be the action of painting. In this system, the actuator is the tool used by the painter to draw, i.e., the brush. The controller would be the painter’s brain, and the sensor would be his eyes. The reader will notice that the proposed example is inspired from the Art and therefore a famous name Leonardo has been chosen for the painter.
- (3) A block-diagram of a controlled system is next presented in a simple manner.
- (4) The video explains what happens when one of the three key elements (controller, actuator, sensor) is missing or faulty, and helps the audience to understand the importance of correctly choosing each element of the feedback loop.

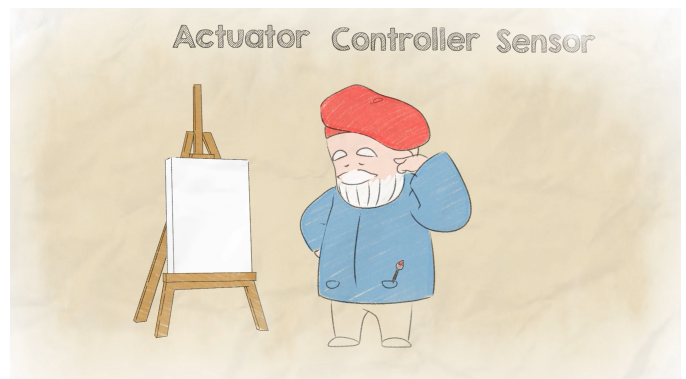


Fig. 1. Screenshot of the first sequence.

In the **second sequence**, once the audience understood the basic control concepts presented in the previous example, the idea is to apply them to a real controlled system such as drones. Thus, this sequence explains how a drone works as a controlled system. It is illustrated that the actuator is represented by its motors, the controller is the microprocessor, and that there are several sensors among which one can distinguish, for instance, accelerometers and cameras. This second sequence is short, but it is very important because it links the basic theoretical notions discussed in the first sequence with their practical application in Control.

A second video explaining the role of disturbances and the concept of stability is ongoing work. This video allows the audience to discover the basic concepts of Automatic Control in a very simple and more attractive way than a formal course. In addition, it can be used during introductory lectures in Control for engineering students, offering a less formal and more visual approach than a standard Control course. In addition, this multimedia approach strengthens

the scope of this paper by encouraging the interest in Automatic Control and Art among a diverse audience.

The structure of this workshop can be adapted with respect to the audience, the available time slot, etc. A minimum 30-minute workshop is proposed based on this video and considering interactions with the audience. An online workshop could be envisaged also. Several additional scenarios are described below, for Open Day events in universities.

- Scenario 1 (45-60min): Start with the proposed video and interactions, and complete with Scratch programming Resnick (2006) inspired from the “Girls in Control” Workshop Jackson et al. (2021), Knorn et al. (2021). A Dragonfly or a Rocketship can be used in Scratch instead of a drone.
- Scenario 2 (60min, requires additional hardware material DJI MasterRobot S1 ground vehicles): Use the proposed video together with additional elements from the workshop “(Re)CreativeRobot” Workshop Stoica et al. (2023). Programming in Scratch on DJI robots can be envisaged or only demonstrator sessions.
- Scenario 3 (45-60min): Use the proposed video as an introduction and continue with any experimental demonstration on Control using an available mock-up system at the university Control lab.

In CentraleSupélec this workshop is intended to be presented to children visiting the flight arena. Several demonstrators on drones and ground mobile robots are available for this kind of events, including funny interactive games.

4. LEARNERS’ FEEDBACK AND LESSONS LEARNED

This section analyses the feedback from the participants and shares some lessons learned during this work.

4.1 Feedback on the “Art & Engineering – Fractals and golden ratio” Workshop

A first occurrence of this workshop was taught by four students of CentraleSupélec in October 2023 for the 28 pupils (14 girls and 14 boys) aged of 13 years old from the secondary school Collège Alain Fournier (Orsay, France). Figure 2 illustrates a small group of children discussing with Arthur, student at CentraleSupélec.

The aim of this session is to arise interest from children towards mathematics while seeking to reduce gender disparities in STEM by encouraging girls to continue scientific studies. The learners and their Mathematics teacher appreciated the workshop. In order to have a quantitative appreciation, a survey was proposed to the participants in the last few minutes of the workshop. A reflection work was undertaken to isolate ten questions useful to quantify the performance of the workshop towards its prime objective. A survey encompassing a question about student gender and a five-dot preference system to answer (1 reflecting a strong disagreement and 5 reflecting a strong agreement) was proposed. The 10 questions are detailed below:

- Q1 - Before the workshop, I had a taste for STEM

- Q2 - Before the workshop, I could not explicit a possible link between Art and Science
- Q3 - The topics addressed during this workshop were interesting enough for me
- Q4 - The content was clear enough and easy to follow
- Q5 - After the workshop, I perceived a link between Art and STEM
- Q6 - This workshop inspire me to pursue studying STEM in high-school
- Q7 - This workshop may become useful for the rest of my studies
- Q8 - This workshop enticed me to look for links between Art and STEM
- Q9 - Overall, I appreciated this Art-based approach of STEM in this workshop
- Q10 - Overall, this workshop inspired me to pursue my studies in engineering.

The results were analyzed by distinguishing three groups: girls, boys and entire class. The average and the standard deviation are illustrated for each question in Fig. 3 and Fig. 4, respectively. The results indicate that the participants appreciated the workshop. A disparity in terms of standard deviation appears for several questions. For boys’ opinions, the effects of the workshop tend to be different compared to girls’ opinions. However, there is no significant difference in terms of mean, as it can be noticed analyzing the results of question Q10.

After the workshop, the children and their Mathematics teacher verbally expressed their satisfaction with the workshop and mentioned that they enjoyed participating in it. Although the effects of the workshop varied among girls



Fig. 2. Picture during the workshop.

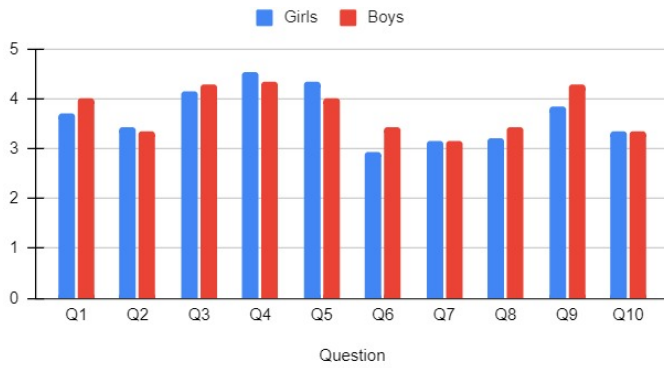


Fig. 3. Mean result per question completed by the 14 girls and the 14 boys.

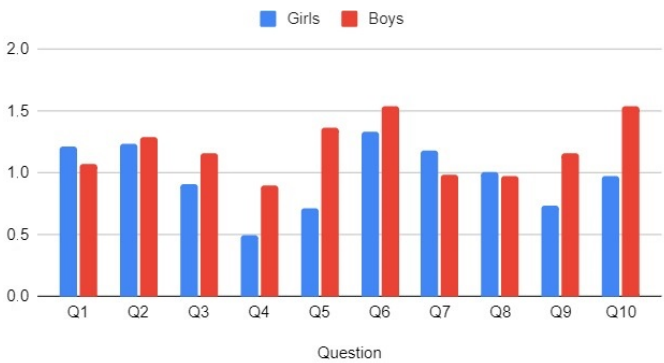


Fig. 4. Standard deviation per question completed by the 14 girls and the 14 boys.

and boys participants, there was no observed improvement in girls' interest in STEM subjects after only one workshop. However, during the survey completion phase, some participants filled in their answers too quickly in order to enjoy a longer break. This practice may have introduced a bias in the collected data. Additionally, the group size is relatively small with only 28 individuals. Besides, it seems difficult for children to project themselves on a long-term on the basis of only one short workshop; therefore, the results might not be as consequent as expected.

4.2 Feedback on the video “Art & Engineering – Automatic Control and animation”

A subtitled version of the video in French was presented to middle-school and high-school participants during the annual national event “Journée Nationale des Cordées de la Réussite” (promoting support and social equity in access to higher education) in Université Paris-Saclay during the workshop “Engineering professions” (in French “Métiers de l’ingénieur”). Three 45min sessions of this workshop were held on Saturday afternoon March 2, 2024 JNCR (2024). During this workshop, the speakers (two undergraduate students and one professor in Control Engineering) presented their career paths, explained the role of engineers, presented numerous engineering applications using videos, and answered the various questions of the participants. Moreover, during this event in 2024, there were 15 different workshops for a young audience in order to introduce various professions to mentees in an interactive manner, through exchanges with tutors (undergraduate students, professors, and industrial speakers).

The video developed in this paper served as an introduction to Control Engineering, and it was largely appreciated by the audience. A survey with 3 questions was completed by the participants, who were both girls (approx. 40%) and boys (approx. 60%):

- Q1 - Would you like to discover more about engineering?
- Q2 - Did you enjoy the video?
- Q3 - Did you learn new things about engineering?

In this diversity and inclusion oriented event, there were 47 participants to the three sessions of this workshop. The survey counts 85% “yes” answers for the question Q1, 94% for Q2, and 77% for Q3, which is very encouraging for a first-time presentation to the general public during a workshop with a large spectrum of engineering topics (i.e., not necessarily focused on Control Engineering).

The participants greatly appreciated the concept of this video combining Art and Engineering in a funny way, and were incredible attentive while watching the video. The questions only had “yes/no” answers. However, some participants wrote encouraging messages on their survey sheet, e.g., “Excellent”, “Cheerfulness”. The main question of several participants was related to a French version of the video, which shows the importance of developing resources for children in different languages.

4.3 Lessons learned

Based on our experience, during the hand-on session of the first workshop, it is recommended that the teaching members interact with the groups of participants to clarify the guidelines. Indeed, numerous questions were asked during this part of the workshop, therefore these face-to-face explanations were of the utmost importance to ensure the correct understanding of the addressed concepts.

In addition, a shorter / more focused survey has to be provided to the participants. It is important to explain to the children that they should complete the survey in a serious mode, as they opinions serve to improve the future sessions of the workshop to be delivered to other children.

Concerning the second workshop containing animated cartoons on Control, several improvements can be carried out to maximize the effectiveness of the outreach for girls in STEM as well as to refine the broadcasting towards people with disabilities. A first idea is to record a feminine voice-over and to replace the main character by a girl. This would then strengthen girls' motivation for STEM by identifying themselves to the main character. Moreover, adding subtitles in several languages appears to be a significant add-on in order to provide accessibility to impaired people or to non-native English speakers.

To have more chances to motive girls to continue within STEM, based on our experience, one idea is to propose regular workshops combining Art and Engineering during different classes at school.

Preparing such workshops requires a lot of resources, e.g., time, motivated persons. Allowing engineering students to be evolved in such outreach activities during their academic projects is beneficial for everyone. Indeed, these activities allow them to acquire pedagogical skills, together

with scientific rigor, persuasiveness, while dealing with diversity, equality and inclusion.

For Control/Mathematics professors, developing such Art & Engineering workshops with their students has an incredible impact on their own creativity, self-questioning, and gives meaning to their profession and vocation.

5. CONCLUSION

This paper proposed two new workshops aiming at increasing the effectiveness of the outreach for girls towards Science, Technology, Engineering, and Mathematics (STEM) by reinforcing links between science and art. A first workshop combining Mathematics and Architecture, designed to provide basic concepts about fractals and golden ratio, was taught in 2023 in a secondary school in France. The participants feedback together with the lessons learned are reported in this paper. A second workshop proposed the *first Control Engineering animated cartoon* <https://youtu.be/BlwebsJofdQ> explaining concepts such as controller, actuator, sensor, block-diagram, etc., illustrated on a drone. The goal of this video is to promote Automatic Control via funny animations. The two proposed Art & Engineering workshops offered encouraging results for the perspective of teaching multidisciplinary approaches. Current work focuses on completing the series of animated videos on Control. New sessions for the workshops will be organized during Open Days in CentraleSupélec and Université Paris-Saclay, as well as in different schools in the Paris region.

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