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An Outline of the Story of Girls in Control and its Success in Motivating Girls Internationally ⋆

Roxanne Jackson *, **Steffi Knorn** **, **Damiano Varagnolo** ***

* *Technical University of Berlin, Germany (e-mail: jackson@tu-berlin.de)*

** *Technical University of Berlin, Germany (e-mail: knorn@tu-berlin.de)*

*** *Norwegian University of Science and Technology, Norway (e-mail: damiano.varagnolo@ntnu.no)*

Abstract: Gender stereotypes often deter women from pursuing STEM-related studies at secondary and tertiary levels of education. Control engineering in particular is an example of a discipline where women are underrepresented in all stages of academia; from undergraduate students through to faculty and technical board members. The Girls in Control workshop targets 10-to-15-year-old girls and aims to educate them about control engineering at a level that is understandable and engaging to stimulate an interest in STEM. Moreover, the worldwide COVID-19 pandemic resulted in new and innovative ways of collaborating and designing outreach programs. The Girls in Control workshop uses online platforms to provide accessibility to girls worldwide by removing language barriers. The workshop runs in almost 20 different languages and the materials are openly available online. The Girls in Control workshop ran successfully at the 21st World Congress of the International Federation of Automatic Control 2020, the IEEE Conference on Decision and Control 2020, the 2021 American control conference, and the 29th Mediterranean Conference on Control and Automation 2021; all of which ran on virtual platforms. Overall, over 500 girls have participated in the Girls in Control workshops in 19 languages with a large amount of positive feedback. A more advanced, follow-up workshop is being tested where girls are challenged further by tackling problems with disturbances and requiring complex control solutions.

Keywords: Multi-cultural interaction, Internet based teaching of control engineering, Virtual outreach, STEM outreach, Outreach for girls

1. INTRODUCTION

Statistics indicate a recognised under-representation of women in fields of Science, Technology, Engineering, and Mathematics (STEM) (Russo and Brittain, 2014). At a bachelor level, engineering in particular is made up of 10 to 40 percent women – exact numbers depend on the engineering disciple and country (National Science Board, 2018).

In control engineering, women are under-represented in all stages of academia from a student- to faculty level (Annaswamy, 2020). Control engineering organisations are however aware of the under-representation in the field: the International Federation of Automatic Control (IFAC) reported in its 2020 technical board report that only 10% of the IFAC technical board members were women; only slightly higher numbers were reported by the Institute of Electrical and Electronics Engineers (IEEE) Control Systems Society (IFAC, 2020; Annaswamy, 2020). The numbers indicate that female students are not only less inclined to study control engineering, but are also less likely to pursue a career in academia after completing their studies (Annaswamy, 2020).

As for the causes of this, gender-stereotypes are known to contribute to deterring women from stereotypically male dominated fields (Schuster and Martiny, 2017). STEM subjects are typically perceived to be more masculine which often discourages girls at a secondary level of education due to a conflict in their individual *self-image* (Makarova et al., 2019). Moreover, although TIMSS (2019) shows that there is no significant difference in gender performance in standardised mathematics and science tests at a secondary school level, girls tend to report lower self-efficacy (i.e., lower beliefs regarding their capabilities) in mathematics and science compared to boys (Hand et al., 2017; Dubetz and Wilson, 2013).

The masculine perception of STEM is persistent and appears in children as early as 6-years-old, i.e., in kindergarten age, before having even a basic understanding of STEM subjects (Makarova et al., 2019). Thus, late primary- to early secondary level education; before entering preparatory years for university studies; is considered

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to be the critical age group for fighting stereotypes to combat perceptions about science and engineering.

To address gender diversity in STEM, there is an evident international need for programs aimed at girls of a critical age to challenge perceived gender-stereotypes and provide hands-on experience in STEM subjects. These activities aim to encourage and motivate girls to consider studying STEM subjects at school, and eventually to consider pursuing a career in the field. McCullum (2014); Walden (2016) discuss a small selection of programs of this description. Many of the existing outreach programs expose girls to a wide range of STEM related problems to show girls that STEM is a rich and diverse field. Additionally, many of these programs are offered nationally but do not provide a platform for conducting the programs internationally.

Our personal experiences as control engineers and the desire to attract more women to study control engineering led to the development of Girls in Control (GiC). The GiC workshop targets 10-to-15-year-old girls and focuses on control engineering specific problems to demonstrate the diverse nature of control engineering. The aims of GiC are two-fold: to encourage girls to develop an interest and passion for science and mathematics through control engineering problems, and to encourage the girls to consider pursuing a career in STEM. Furthermore, the GiC workshop aims to remove language barriers and encourage international participation. The workshop runs virtually in a range of languages to provide an educational experience for girls despite their language knowledge, or country of residence.

In this manuscript we discuss the general and important aspects of the GiC workshop and how it is implemented. We furthermore discuss the success of the workshop so far and propose how we plan to extend the workshop in the future with more materials and more diverse control engineering problems. It is important to note that a lot of pedagogical research indicates that there are more similarities than differences between the technical abilities of girls and boys. The workshop material is not explicitly gendered and can be used to create a fun learning environment for girls and boys. Our intention in running a *Girls* in Control workshop is to address the gender gap in control engineering by offering an outreach program that actively targets the issue.

2. THE IMPLEMENTATION OF GIRLS IN CONTROL WORKSHOPS

The GiC workshop provides an opportunity for girls of 10-15 years of age – independently of their cultural background or spoken language – to learn about control engineering through an engaging online workshop.

2.1 How We Teach Control

In any attempt to teach effectively, it is important to appeal to the level of the audience. This means that when attempting to teach control, we aim to neither underestimate nor overestimate the knowledge of the students. Due to using a virtual platform it is especially important to keep the participants engaged since it is particularly easy for a participant to tune-out, start playing with their smart phone, or completely abandon the workshop altogether without the workshop coordinator noticing. As pointed out in Abramovitch (2019), when a student disengages from the material, we have lost an opportunity to inspire a new generation, and may have, in fact, caused more harm than good.

To appeal to the abilities of our audience, we make the following assumptions when addressing the students in the GiC workshops:

- They have basic mathematical knowledge like being able to understand a proportional relationship, or an error term (the difference between two values). We do not assume that the students have any knowledge of differential equations or calculus and we do not show any equations during the workshop.
- They are comfortable with some engineering terminology, e.g., automation, robotics, and programming.
- They are self-motivated and thirsty for knowledge; they have chosen to participate in the workshop after all.

Within these assumptions we thus aim to teach the girls about the basic elements of a feedback loop and how to implement a solution to a control problem. During the workshop, the girls watch several videos covering control theoretic principles. An important aspect of these videos is that all of the examples are intuitive and put the girls in the control loop to keep them engaged with the problem. We chose examples from every-day life so that children from different cultural backgrounds can understand. The videos are audio-visual without text or equations. Thus, all girls are exposed to the same videos and only the voice-over is adapted for each language.

Part 1: What is Feedback? In this video, we help the girls understand control by providing a "human in the loop" example of a feedback loop. To this purpose, we use the example of taking a shower, which we have found to be a (mostly [1]) universal example and can be explained by using the block diagram in Figure 1. In this example we define the important elements of a feedback loop:

The Plant is the system that we wish to change because it does not meet the specifications. In Figure 1 our plant is a shower and is represented by the shower icon.

The Sensor detects or measures a physical quantity. In Figure 1 our sensor is our hand feeling the temperature of the water.

The Controller uses the sensed value and compares it to an expected value and decides how to change the operation of the plant. In Figure 1 the controller is indicated by the brain icon because when we shower, the temperature information is processed by our brain and registered to be too hot, too cold, or just right. The brain then decides on the appropriate adjustment to make the water colder, hotter, or make no change, respectively.

[1] In some countries, such as Brazil, the water is heated while flowing through a heating coil built into the shower head. This usually only allows for the settings: on (winter) or off (summer). The example where the temperature is carefully adjusted may not be understood well by the participants from these countries.

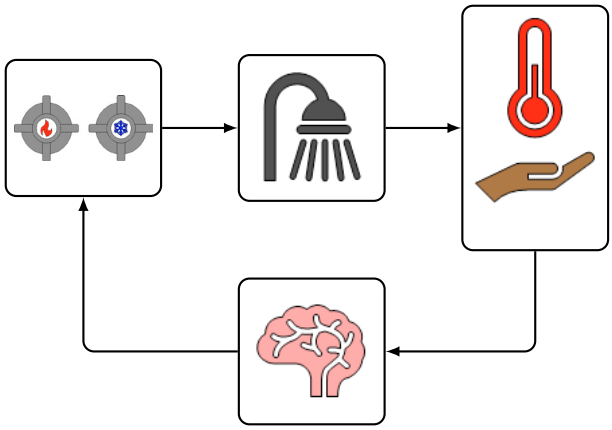

Fig. 1. Block diagram of the shower feedback cycle. The shower is the plant, the thermometer and hand are the sensor, the brain is the controller, and the hot-and-cold taps as the actuator

The Actuator physically creates change in the system. In Figure 1 the actuator is the pair of taps which indicate hot and cold because we adjust the taps to change the temperature of the water.

Part 2: Control in a Game of Chase Using the fundamental understanding of a feedback loop and forming it in an engineering block diagram allows the extension of this system into other control examples. In this video we encourage the girls to consider the feedback loop for another "human in the loop" example – playing a game of chase.

In a game of chase (also known as tag or tips), one person is *it* and runs after the other players trying to tag them. The first person tagged is the new person who is *it* and the game continues.

We use the block diagram in Figure 2 to again help explain the role of the plant, the sensor, the controller, and the actuator. In Figure 2, the task is to chase after the other player/s, we use our eyes as the sensor to see where we need to run, we use our brain to interpret this information and determine in which direction we should run, and we use our legs to physically run after the other player.

Moreover, in this video we emphasise the importance of each element in the feedback cycle by investigating the effects of what happens when we take an element out of the feedback cycle. A great example of a similar experiment is presented in Fontanive et al. (2014).

Part 3: Further Concepts in Control In this video, we introduce further concepts of control and discuss the idea behind different control techniques by once again relating the control techniques to a game of chase.

For explaining P-control, we first discuss how our running speed changes when trying to catch someone in a game of chase. When we are further away, we run at top speed to approach them as fast as we can, then as we get closer we slow down so that we can tip them without running past them or running into them. We explain this concept by the diagram in Figure 3. Thus, explaining that the effort

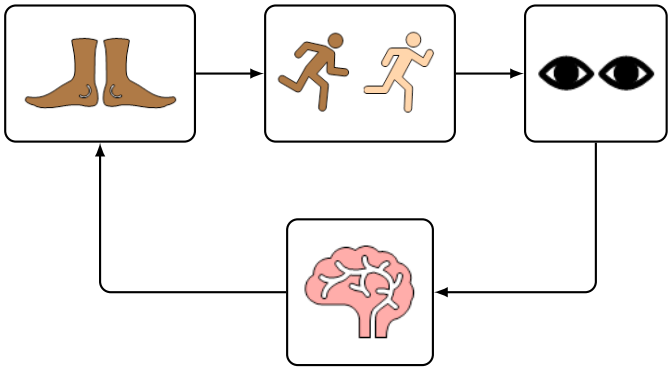

Fig. 2. Block diagram of the feedback cycle when playing a game of chase.

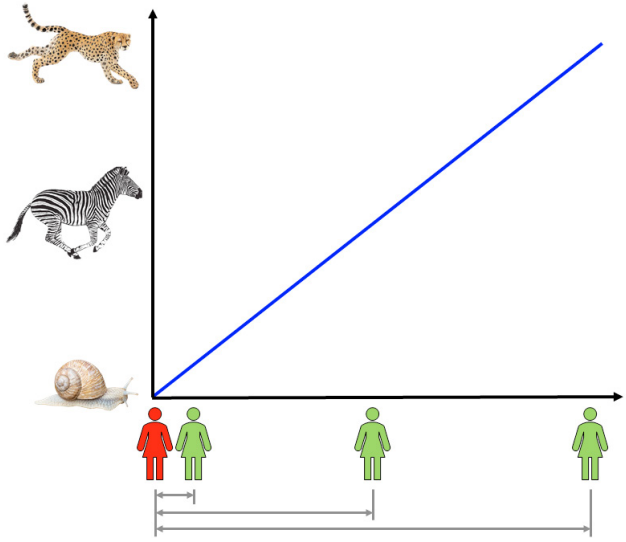

Fig. 3. An image to explain P-control when playing a game of chase. When the chaser is further away, they run quickly and as they approach their target, they progressively slow down.

of our control action is proportional to how far away we are from the target.

We similarly use an example of playing soccer (also known as football) to explain feed forward control. In this example we explain that instead of using the distance from the target (or error) to determine your direction and speed, if you have prior knowledge of how you expect something to act, then you can react accordingly. For example, if you are trying to chase a moving soccer ball and you can see how fast it is rolling, then you can run to where you think it will be instead of where it is at that moment. See Figure 4 for an example of how the chaser *follows* the ball when playing soccer with a feed forward approach.

2.2 A Task in Control: Creating a Game of Chase

During the bulk of the workshop the girls use Scratch, a graphical drag-and-drop programming language accessible through `https://scratch.mit.edu/` to implement their first controllers for an automated game of chase. The girls are encouraged to implement advanced features such as

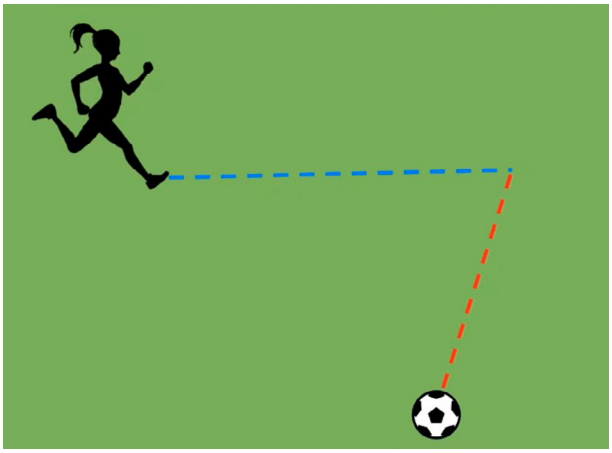

Fig. 4. An image showing the outcome of using feed forward control when playing soccer, where the dotted lines show the trajectories of the ball and the player.

scoring systems, adaptive dynamics, and consider how to implement more advanced control techniques. The workshop helpers during this time help to problem solve with the girls by showing them how to use the Scratch functions to aid in their control solutions.

In the past, we have even seen some girls with previous programming knowledge implement a P-controller solution. These advanced solutions have lead to the development of a more advanced control problem; explained further in Section 4.

2.3 Control Engineering Guest Speakers

Gender-science has shown that gender stereotypes associated with STEM subjects hinders the self-identification and self-concept of female students and hence deters them from choosing STEM subjects; even if they align with their interests (Makarova et al., 2019). Thus, female representation in STEM is an important part of the GiC workshops. We invite professionals working in control to speak about themselves and their careers. This provides an opportunity for the girls to interact with control engineers and see how creative, passionate and challenged they are in their line of work. By showing female representation in STEM, we aim to contribute to small changes to the overall perception of gender stereotypes in STEM; specifically control engineering.

2.4 Internationally used Materials

Running the workshop virtually removed geographical barriers. But to reach a larger span of girls the new problem became language barriers. Thus, the idea to develop the workshop materials in many languages came to fruition. Through colleagues and connections, control engineers from around the globe were contacted and encouraged to develop the workshop materials in their mother tongue.

Since all videos are made using only visual elements, the same teaching materials are used for every language and only the voice-over language is adapted for each video. Additionally, Scratch is available in many languages to accommodate for the students' language requirements.

Using Scratch to program has additional benefits by having the option to choose from 60 languages which are the most used languages in over 150 countries. They also offer a function to add or improve a language translation. By using the language adapting programming language, Scratch, and the video materials with voice overs for teaching about the basics of control, the language barrier is successfully removed from workshop participation.

3. WORKSHOP PERCEPTIONS AND LESSONS LEARNED

The virtual workshop ran for the first time in July 2020, during the 21st IFAC World Congress, in six parallel sessions, i.e., English, French, German, Italian, Norwegian, and Portuguese. Our first workshop attracted almost 100 girls from over 20 different countries. In December 2020, for the IEEE Conference on Decision and Control, the GiC workshop ran again in 17 languages and popular languages like English and Spanish were offered at several different times to accommodate for participants in all time zones. For this iteration of the workshop we attracted around 350 girls and gained further interest from colleges to run the workshop alongside future conferences. Over May and June 2021, for the American Control Conference (ACC) and Mediterranean Conference on Control and Automation (MED), the GiC workshop ran again in many languages and attracted hundreds more girls. On all occasions, the GiC volunteers reported that there were many happy faces and interesting questions. The solutions produced in such a short period of time were creative and clever. The feedback from the participants and their parents was overwhelmingly positive and many girls expressed an interest to participate in future GiC events.

Additionally, in a special workshop session at MED2021 collegues, parents, and interested control engineers had the opportunity to learn about how the materials were put together and learn about the logistics of the workshop in order to run the GiC workshop themselves or use the materials for similar educational purposes.

The high number of participants showed that there is a need and an interest for such activities and a void that was not filled before. Moreover, from running the workshop several times now, we have noticed additional voids:

(1) Control engineers/colleagues wanted to join to learn about the workshop and how to teach control at a simple level, or to get inspiration for their own teaching but we are however responsible for protecting the personal data of the children and must decline such inquiries. This demonstrates that there should be an additional educational element of the GiC workshop for people who wish to teach the workshop or create similar educational resources. Hence, the special workshop session at MED 2021.
(2) About 50% of the participants reported that the programming exercise was too simple (specially older girls and girls with programming experience) and hence asked for more challenging material. This demonstrates a need for similar control engineering exercises but with a more challenging control exercise. We intend to fill this void by running an advanced workshop which is explained further in Section 4.

4. PLANNED ACTIVITIES FOR THE FUTURE

We plan to continue to run the GiC workshop frequently in the future with the goal to involve more schools and promote in-person workshops following the COVID-19 pandemic while continuing to run the workshop virtually for accessibility reasons.

Moreover, due to the continued interest from previous participants of the GiC workshop, and the feedback that the programming exercise was, to some, too basic, we have developed and begun testing an advanced workshop option. In the advanced workshop, the girls are given a different story with more components to control. The workshop develops around the story of an alien that has crashed on Earth and needs precise temperature control in order to prevent an intergalactic war. Additionally, the problem of controlling its blood sugar level by feeding it special cookies at discrete time instances is also introduced. Further, to add complexity, the dynamics of the body temperature and the blood sugar are coupled. The girls are given an air conditioner and a heater as well as the option to feed cookies and their task is to find a controller to regulate the temperature of the alien and keep the blood sugar at an acceptable level.

In order to further increase the difficulty and challenge the participants more, the workshop also includes exercises where *(i)* an external disturbance is introduced (the sun shining into the lab, heating up the room further), *(ii)* the variables to be controlled cannot be measured continuously (for instance, the blood sugar may only be measurable at discrete time instances and may include other risks or costs such as annoying the alien) or *(iii)* the control costs should be kept minimal (the heating and air conditioning costs may be considered as well as supposedly specially made, expensive, alien-friendly cookies).

Additionally, we endeavour to develop a practical experience for girls where they can purchase cheap and easy-to-use hardware to apply control to a real, dynamic system. This will be a harder workshop to run virtually due to unexpected errors when using hardware. However, we believe that this workshop experience will be fruitful for those girls who are tactile learners.

5. CONCLUSIONS

The GiC workshop has been a great success during the time of the COVID-19 pandemic and we wish to continue running both virtual and in-person workshops for GiC in the future. We will continue to challenge gender stereotypes in STEM and encourage more girls to pursue their passions.

5.1 How can you help?

If you are interested in developing materials for the GiC workshop in your mother-tongue, or would like to get involved with running the workshops and similar activities please contact us on `gic@ifac-control.org` (it is easier to contribute than you think). We also need volunteers to help with the materials we make available online, and for creating new workshops.

We are always looking to make the workshops better and more inclusive. If you have any ideas or feedback we would be happy to hear from you.

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