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Camp Euclid: A Research Experience for Youth—in a Virtual Environment

Juliette Benitez, Nickolas A. Castro, and David T. Gay

Introduction

Camp Euclid is a research program for pre-college students that Euclid Lab has been running online since 2010. Students collaborate on unsolved problems in mathematics, working together online, asynchronously and in real time, with mentor facilitation.

Euclid Lab's outreach focuses on introducing unsolved research problems to the general public and especially to youth—and actively encourages people from all backgrounds to try to solve them! Two of these authors, Juliette Benitez and David Gay, founded Euclid Lab in 2010 as an independent not-for-profit mathematics research organization with Camp Euclid as its flagship outreach program. The second author, Nick Castro, has worked with Camp Euclid since 2016, first as a graduate student mentor and now as the lead senior mentor.

As we hope to inspire others to create similar programs, we would like to tell you all about Camp Euclid: how it works, why it's a great experience for students and mentors alike, and our basic philosophy behind it. See `https://euclidlab.org/programs/camp-euclid` for more details.

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From the Campers

We begin with some quotes from past participants.

"I'm Ollie Thakar, currently a rising sophomore at Princeton planning to major in math, and I participated in Camp Euclid 5 years ago…. I loved the open-endedness and the fact that students were encouraged to think creatively. Camp Euclid was one of many ways I was inspired to pursue pure mathematics, and in particular I have become very interested in math pedagogy as well…. The collaboration that we faced in Camp Euclid is unlike any other I've ever encountered in math education ... making math writing better, more precise, and more rigorous is necessary yet workshopping proofs is still rare in standard education. The balance of working on one's own and with the help of others was perfect."

From Shashank Rammoorthy, now a junior at Stanford studying computer science and math: "I had a fantastic time at Camp Euclid. It was extremely motivating seeing the high-schooler researchers in my group coming up with conjectures and proving them week after week, and Camp Euclid imbued in me a love for proof-based math that continues to this day."

Super-Inclusive Philosophy

All aspects of our program, from the group structure to the mathematical content to our admissions and financial aid process, are designed to be as inclusive as possible.

Student-Driven, Mentor-Inspired

Camp Euclid is organized into groups of ideally five to seven students and three mentors. The lead mentor has a PhD, the junior mentor is a graduate student or has a master's degree, and the assistant mentor either has or is working on a bachelor's degree.

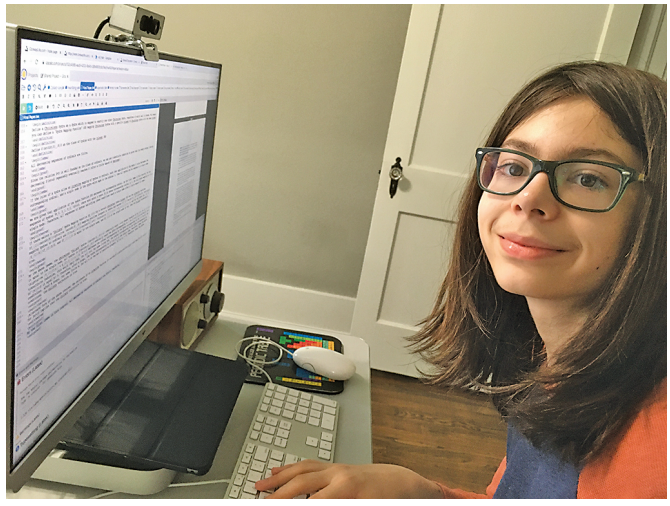
Figure 1. Current camper Mauro Araya, thinking about the Collatz conjecture.

Virtual Research Environment

Students work both offline and online, with online work involving four hours per week, over the course of six weeks, in face-to-face video meetings, and asynchronous collaborative work on LaTeX documents. We currently work within Google's G Suite for Education for meetings and communication and use Co-Calc for collaborative writing and computation.

Online and Offline Activities

These online resources make it possible for students from around the world, from big cities to tiny rural communities, to work together without leaving their homes. For some students the opportunity to leave home for a special summer program is a valuable one, but for many students and for many reasons it is not an option.

To help keep this from being an all-day-in-front-of-the-computer experience, we spread the program out over six weeks; we estimate that students put in at least ten hours a week of work on Camp Euclid, and some a lot more, but only four of those hours are in front of a webcam. We encourage them, for example, to work offline, outdoors, on pen and paper as much as possible, and transfer their thoughts to the collaborative document setting only after a nontrivial amount of offline time.

Students Work on Unsolved Problems

The mathematical activities at Camp Euclid are very much at right angles to those in an everyday classroom experience, so that students with diverse academic backgrounds can all contribute meaningfully to mathematical research.

Each group of students chooses two or three unsolved problems to work on during the program. They work on these problems, then they write up whatever they discover. The only criteria for the problems that we insist on are that every member of the group should easily understand the statement of the problem and that a majority of the members of the group should think that the problem is interesting.

Thus, for example, we have no objection to students working on the Goldbach conjecture, since all of our students will know what prime numbers and even numbers are. We make it very clear to our students that there is no expectation that they will solve the problem they set out to solve. "Working on the problem" typically means formulating special cases, doing sample computations, changing the statement of the problem in interesting ways to understand the logic and see if it becomes more tractable, and exploring numerous interesting lines of reasoning that often end up as dead ends but are still informative.

We emphasize that when you work on a problem the most likely outcome is that you will make incremental progress on some related problem, that you will find new and interesting questions to ask, and that you will definitely learn something, even if that something is not the answer to the problem you set out to solve. Thus the problems are really anchors and guides for collaborative mathematical exploration. An important mentoring task is to help students realize when they have made discoveries, and that these can be formulated and written down in the form of conjectures, questions, lemmas, propositions, theorems, and, most importantly, proofs.

Admissions: Fun and Easy

We have a simple and effective admissions process. Applicants submit basic identifying information and then have a 15–20 minute online meeting with a Camp Euclid mentor.

As preparation for the meeting, the applicants are instructed to find an unsolved problem in mathematics (we have some listed at `https://euclidlab.org/` unsolved) and think about it for an hour. That then forms the basis of the discussion in the meeting. We are trying to ensure, most importantly, that the student is enthusiastic about the whole process and can manage the technical aspects of the online research environment.

At the end of this meeting, to which parents or guardians are also invited, the applicant has had a chance to discuss exciting mathematical ideas with a mentor and discuss and experience the inner workings of Camp Euclid. The applicant and the mentors both end up with a pretty clear idea of whether the program will be a good fit.

Full-Need Tuition Waivers

A crucial mission of Euclid Lab is to make Camp Euclid affordable to all. Currently participation in Camp Euclid costs $1,400 per student; these costs are used to pay mentors and cover auxiliary costs, and to maintain enough funds to offer financial assistance to students who cannot afford the full fees. After being admitted, we ask students if they would like to apply for financial aid. We do not do this earlier because we want the entire admissions process to be need-blind.

Then our financial aid application process is very simple: we ask the applicants and their parents how much of the $1,400 they can afford to pay (including a brief explanation of how the fees are used and our honest efforts to support the full financial need of all participants) and then we do our best to offer partial to full tuition waivers so that they pay only the amount they can afford.

In fact, we are very proud to report that, since Camp Euclid's inception, we have always been able to meet all participants' stated financial needs. We have many students who pay the full fees and many students who pay nothing or close to nothing for the program. (We have been partially supported in some years by the AMS Epsilon Fund and by some individual researchers' NSF grants.)

First Day

Camp Euclid participants come to their first day of camp prepared to discuss three unsolved problems of their

choice. The students take turns discussing their questions, which includes any progress they may have made in how to think about or approach a problem. During this process, everyone is encouraged to freely ask questions.

First Week

In the first few meetings students take turns discussing these questions and here the mentors face the following challenges: (1) slowing speakers down so everyone can follow their reasoning; (2) making sure the students explaining their ideas do so with appropriate mathematical precision; (3) ensuring everyone in the group is paying attention and following what the speaker is saying. These three issues will be encountered again and again throughout the camp.

The students proceed to discuss all of the questions they find interesting for two to three meetings, allowing for other students in the group to understand the questions and decide which ones they find interesting. By the end of Week 1 we pick three questions, based on participant and mentor preferences, and aiming for some subject matter balance (e.g., geometry vs. combinatorics vs. number theory).

Next Couple of Weeks

During Weeks 2 and 3 the students attack the problems however they see fit. At this point the mentors strongly discourage the students from doing any background reading, as this can be a distracting time-sink. We want them to tackle the problems with the skills that they already have, and we want the students to let their creativity and critical thinking run free and intermingle in ways not typically seen in other parts of their mathematical education.

This is also the phase when it is critical for mentors to focus on promoting a positive group dynamic, especially so as to engage the more reserved students; it is crucial to make sure all participants are regularly active in all the discussions. We not only aim to have the students understand what is being said, but strive for each student to be engaged in (most of) the discussions each meeting. We find it useful to end each meeting with a "task list" for each student, ranging from writing up a specific, previously discussed argument to present to the group in the following meeting, to investigating patterns in sequences given by one of the other students' python program.

The mentors try to cultivate a fun environment where teenagers (or sometimes, not quite teenagers) feel free to voice their ideas. This requires a balancing act between moderating the discussions so that everyone is involved and letting the discussion flow freely so that people's ideas are not stifled. It takes great care and attentiveness to the subtle (and sometimes not so subtle) cues, which can sometimes be lost in the online environment.

Last Three Weeks

At the beginning of Week 4, the halfway point, the groups shift their focus from thinking about their unsolved questions to writing up their results. They learn to use LaTeX and collaborate with each other, this time in a written format, to produce a single, edited document with all of the group results. During this part of the camp, the role of the mentors flows between editor, moderator, LaTeX guide, collaborator, and everywhere in between.

Figure 2. Exploring unsolved problems at a Euclid Lab science festival booth; a face-to-face Camp Euclid-style event for all ages.

Of course, during this process the students continue to make progress on their questions, but the main objective is to get them writing their ideas in their own words and to read their collaborators' work carefully and thoughtfully. As we all know, a great deal of mathematical understanding comes when writing the details of an argument, and one can never start writing too soon!

DIY: How to Help

Finally, here are two ways in which you can help. (1) Help us and others build and maintain lists of unsolved problems which can be quickly understood by high school students. (2) Set up a similar program on your own or collaborate with us on a joint project! For example, a Camp Euclid-type program could run (a) in a residential-camp format, (b) in a classroom, (c) at a science festival booth (as shown in Figure 2) or, (d) at the other extreme, online but entirely asynchronously with very low bandwidth requirements.

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Figure 1 is courtesy of Gregory Araya.
Figure 2 and photo of Juliette Benitez are courtesy of Juliette Benitez.
Photo of Nickolas A. Castro is courtesy of Nickolas A. Castro.
Photo of David T. Gay is courtesy of David T. Gay.

Math SWAGGER: Building a Virtual Community

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Background

The Mathematics Summer Workshop for Achieving Greater Graduate Educational Readiness (Math SWAGGER—www.mathswagger.com) is a five-week virtual summer program for any underrepresented student (including women, underrepresented minorities—African Americans, American Indians including Native Alaskans, Latinxs/Hispanics

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