The Hippocampe Workshops: from the Experience of the IREM in Marseille to that of Roma Tre University

Matteo Acclavio*

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Sommario

The purpose of this report is to present the educational mathematics laboratories "Hippocampe." We will describe the structure of the laboratories, the experience at the IREM in Marseille where they originated, and, finally, the workshops conducted in 2016 and 2018 at the Department of Mathematics of Roma Tre University.

1 Introduction

Considering the unparalleled rise in the study of mathematics (and computer science, which has grown from this development) over the last century, the math curricula in middle and high schools are decidedly outdated. A large portion of the skills required of students risks being obsolete today given the widespread nature of technology, now omnipresent in daily life, while teaching logical reasoning and computer science still occupies a minor role.

This has led to an identification of the subject with a set of "ad hoc" tools to solve specific (and abstract) problems rather than as a language to formalize reasoning. In the face of this issue, teachers are often reluctant to include proofs or exercises requiring theoretical reasoning in assessments. Mathematics teaching needs a new balance: the ability to apply algorithms and calculation procedures to solve specific tasks should always be accompanied by the ability to decipher or create new algorithms. In particular, alongside the well-known problem of what in English is called *innumeracy* (inability to perform calculations), there is an increasing need for basic "computer literacy."

During the post-World War II period, different countries attempted curriculum renewals, such as "New Math" in the United States and "Mathématiques Modernes" in France, aimed at increasing mathematical literacy and the spread of sciences. These experiences proposed an approach to mathematics based

*INRIA Saclay — LIX École Polytechnique

primarily on reasoning and proof. The development of calculation skills was conceived as a consequence of these abilities. Unfortunately, these experiences failed and were followed by strong criticism due to excessive formalization and the excessive abstractness of program content.

More recently, this approach has been revived in the form of workshop in various experiences such as the *Hippocampe* workshops (originated within the IREM of Marseille [2]), the *Math.en.Jeans* workshops [3], the *MathC2+* workshops (organized by the Fondation Sciences Mathématiques de Paris and the association Animath [1]), and *Research Situations for the Classroom* (studied by the team "Maths-à-modeler à Grenoble" [4]). Thanks to their laboratory format, these educational experiences allow students to experience a new form of approach to the subject: the student has the opportunity to develop their knowledge in a dynamic, assisted scientific research environment. These experiences represent valuable tests on how new curricular topics can be developed for adaptation to school teaching.

2 What is a Hippocampe workshop?

The Hippocampe workshops were born in 2005 within the IREM[1] (Institute of Research in Mathematics Education). These workshops aim to prevent secondary school students from becoming disengaged from scientific subjects and, more generally, to promote scientific culture. The central idea of the Hippocampe workshops is not to present mathematical results to a non-academic audience but rather to place students in the position of being the main actors in the research process, allowing them to build their own knowledge instead of passively learning it.

Each workshop involves hosting a class (20-30 students) from high schools for three consecutive days within the university for an introduction to mathematics research. After presenting some research topics with related open questions, students are encouraged to develop their responses to the presented topics by working in small groups, discussing, and comparing experimental results under the guidance of a small team of supervisors. At the end of the three days, students will present posters containing their findings to an audience of teachers, students, and researchers from the hosting department.

2.1 Pedagogical Objectives

Students involved in a Hippocampe workshop encounter, for the first time, a different method for studying mathematics. They become participants in the knowledge production process, constructing the necessary formalism to express both the problem and the solution. The understanding of topics happens in tandem with research, allowing the final result to be perceived as their own rather than as an established truth handed down by an intermediary.

Each workshop aims to enable students to develop the following skills:

[1] `http://www.univ-irem.fr/`

- Initiating research independently;
- Developing new study methods to understand new concepts;
- Adopting a critical approach to the results obtained;
- Being able to communicate their discoveries, both in written and oral form.

Furthermore, the laboratory allows students to immerse themselves in the university environment in a different context than "open days": students are not just visitors; they are part of the department's student community.

2.2 The Role of Supervisors

The supervisor serves as a research guide throughout the workshop, suggesting directions for groups through questions and testing the actual understanding and consistency of discoveries. The supervisor represents a means of verification and stimulation for students' discoveries by proposing questions that help them understand the topic and prevent them from making mistakes or straying too far from the chosen subject.

The workshop does not involve any form of lecture-based teaching. The supervisor's role is to stimulate students without forcing them to follow predefined reasoning, leaving them complete freedom to make mistakes; understanding the cause of errors and correcting them is part of the learning process. By the end of the workshop, the student will have developed their own method of understanding, which can then be applied to the study of mathematics and science in general.

2.3 The Experience of IREM in Marseille

Initially started as a project within the biology department, the first mathematics Hippocampe workshop took place at IREM in Aix-Marseille in 2005, with an increasing number of workshops each year. Currently, the Pythéas laboratory at IREM offers about fifteen workshops a year. Partners of the laboratory include the Faculty of Sciences at Aix-Marseille University and the Institute of Mathematics of Marseille (I2M), from which most of the supervisors participating in the workshops come. Another partner is the CIRM (Centre International de Rencontres Mathématiques), which occasionally hosts poster presentation sessions during conferences, involving external researchers from other universities and allowing students to interact with professors and foreign researchers.

Since 2006, some workshops have also been offered to primary schools and the *École de la Deuxième Chance de Marseille*, a school for young people aged 18-25 who have left the school system without a diploma or qualification.

From the IREM experience in Marseille, the Hippocampe workshop model has spread throughout France, and workshops are also organized at IREM in Brest (since 2007), Lyon (since 2009), Toulouse, and Nice (since 2011). Since

2016, for the first time in Italy (and outside France), two Hippocampe workshops have been held at Roma Tre University.

3 How a Hippocampe workshop Works

Each workshop proposed by IREM in Marseille involves a group of supervisors, including a coordinator who chooses a common theme for different research directions. Typically, these roles are filled by professors, researchers, or doctoral students, but also students involved in study programs aimed at teaching.

In the first part of the workshop, students from colleges or lycée[2] are welcomed into the laboratory. After an introduction to the laboratory, faculty, and university, the research topic is illustrated by the workshop coordinator. During this presentation, specific problems or possible research directions are suggested. For example, some proposed topics include "Graphs and Geometry," "Maths à la carte," "Games, Mathematics, and Some Dances," or "Fractals" (for a complete and updated list of workshop themes, see the page `https://hippocampe.irem.univ-mrs.fr/Planning`).

The students then divide into groups of three or four elements[3]. Each supervisor typically accompanies two groups, providing stimuli for reflection and discussion.

Each group then follows its research path, which may or may not be predetermined. The first task for students is to "get familiar" with the given problem, understand the context to be examined, and identify points of interest. During this phase, the first fundamental research problem emerges: identifying (and defining) the necessary mathematical objects.

Throughout the research process, students formulate their conjectures, conduct tests, and put their theories to the test. Often, they encounter errors, incorrect assumptions, or inaccurate deductions, providing an opportunity to discover the non-linear nature of research, which is rarely observed during lectures.

Moreover, students' need to define their formalism encourages them to reevaluate the importance of formalism itself: providing a correct and precise definition or writing a statement coherently and understandably. Over the next two days, research is increasingly accompanied by formalization work.

On the afternoon of the second day, the groups present their work to other students in small presentations. This serves as a test for the clarity of their results among an audience unfamiliar with the topic. In this phase, students often realize the lack of clarity in some definitions or arguments, and they receive feedback to improve their presentation of results.

The third day is dedicated to producing posters and presenting them. Posters are designed to provide an overview of the problem and the solutions found and as a necessary support for students' explanations. During the poster session, students, researchers, and teachers from the department are involved,

[2]For Italian students, the age group corresponds to high school.

[3]Experience shows that smaller groups may lack sufficient stimulus, while larger groups tend to be more prone to distractions.

discovering students' research results by asking questions, clarifying concepts, and discussing conjectures or other potential research paths.

Students hosted at IREM have access to three rooms, a computer lab to research potential images for posters, and the materials needed to prepare the posters. Some posters produced by the workshops are available on the Pythéas laboratory website `http://pytheas.irem.univ-mrs.fr/hippocampe/`.

Teachers of the participating classes are usually present during the workshops but do not participate in supervising the students.

4 The Workshops at Roma Tre University

The first workshops at Roma Tre University were conducted in 2016 as a personal initiative of the author[4], enthusiastically welcomed by the IREM in Marseille and realized thanks to the availability of Prof. Andrea Bruno (then responsible for the *Progetto Lauree Scientifiche* of the department) in coordinating relations with the department. The classes for this experimentation were contacted through personal networks with the teachers of the involved classes.

In 2018, two more workshops were held, this time coordinated thanks to Prof. Luca Biasco (responsible for *Progetto Lauree Scientifiche*) and Prof. Roberto Maieli (responsible for *Alternanza Scuola Lavoro*), with students contacted through the channels related to Roma Tre University's work-study program.

The structure of the workshops was maintained almost unchanged except for the choice to anticipate the poster presentation to the morning of the third day.

For example, the following is a list of workshop themes and the tracks developed:

- The paradoxes of Zeno: Is it true that Achilles will never reach the tortoise?

  [Study of the convergence of geometric series starting from the dichotomy problem];

- The discovery of perspective in art: When drawing in perspective, non-horizontal parallel lines meet at a point called the focus.

  [Some observations on projective geometry];

- Constructive and non-constructive proofs: In Rome, there are at least 2 people with the same number of hairs, and this can be proven without counting the hairs of each person. Transcendental numbers are numbers that are not the root of any polynomial with integer coefficients. How can we prove they exist?

  [Using Cantor's diagonalization to prove that polynomials with integer coefficients are countable];

[4] At the time, ATER at Aix-Marseille Université.

- Hilbert's Hotel: How to accommodate new guests in a full hotel with an infinite number of rooms?

  [Prove that there is always room for a countable infinity of guests, but not for a continuous infinity];

- Goodstein's Sequence: The Goodstein series $G(n) = \{g(i, n)\}$ is constructed starting from an integer n as follows:

  - $g(1, n) = n$
  - $g(k, n)$ is the number obtained by replacing the number k with the number $k + 1$ in the hereditary base k representation of $g(k - 1, n)$ and subtracting 1
  - if $g(k, n) = 0$, then $g(k + 1, n) = 0$

  The sequence tends to 0 for the values 2 and 3. Is it true that it tends to 0 for any natural number?

  [The proof requires introducing the notion of ordinal numbers, their operations, and order];

Photos of the posters are available on the webpage:`http://matteoacclavio.com/ProgettoHippocampe/HippoInf16.html`.

Stage Hippocampe: Polygons and Polyhedra (April 2016)

To the students of the 3^a C of the Liceo Scientifico Enriques in Ostia, the theme "Polygons and Polyhedra" was proposed for the workshop. This workshop studied some combinatorial and geometric properties of polygons and polyhedra.

The following tracks were developed:

- The shape of tiles: If you want to pave a floor with a single type of tile, which shapes can be chosen?

  [Polygons that tessellate the plane and how to create new shapes using the minimum drawing method];

- The coin and the manhole: Why are street manholes and coins round? What properties does this shape have? Are there others with the same properties?

  [Figures with constant diameter and how to construct a figure with constant diameter starting from any polygon];

- From 2D to 3D: How to design a pattern for a dress? How to cut cardboard to create packaging with a desired shape? How many ways are there to cut the same polyhedron?

  [Study of planar developments of polyhedra and their enumeration: pyramid, cube, and conjectures on any convex polyhedra];

- Polyhedral graph: Projecting the skeleton of a polyhedron creates a graph. How is this graph made? What properties does it have? And starting from any graph, is it possible to reconstruct the skeleton of a polyhedron it shadows?

  [The shadow of a polyhedron is a planar 3-vertex-connected graph];

- Platonic solids: Platonic solids are named after Plato, who mentions them in the Timaeus, but they were already discovered by the Pythagoreans. There are 5: tetrahedron, cube, octahedron, dodecahedron, and icosahedron. They have equal faces made of regular polygons. What are their characteristics? Are there others? Why?

  [Research the proof of the non-existence of other regular polyhedra using Euler's formula $V + S + F = 2$ or the method used by Euclid];

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Stage Hippocampe: Mathematical Billiards (January 2018)

To the students of the 3^a A and 3^a C of the Istituto di Istruzione Superiore Statale Alberti in Rome, the theme "Mathematical Billiards" was proposed for the workshop.

At the beginning of the workshop, the problem of finding a minimal path between two points in a half-plane, reflecting on the line that delimits the half-plane, was studied. From this problem, the concept of trajectory and the rule for studying reflected trajectories in a mirror or billiard table "angle of incidence = angle of reflection" was introduced.

- The square billiard table: Given a starting point for the ball and a second destination point, how can you determine where to bounce the ball to make a certain number of cushions before reaching the destination point?

  [Study of billiard trajectories in the plane using the reflection method];

- The elliptical billiard table: How are the trajectories formed in an elliptical billiard table? If a pocket is placed at one of the two foci, where should the ball bounce to fall into the pocket?

  [Any trajectory passing through one focus passes through the second focus; trajectories external to the foci remain external, drawing an ellipse, while those internal remain internal, drawing a hyperbola];

- Circular billiard: what are the trajectories in a circular billiard? If a hole is placed in the center of the circle, is it possible to send the ball into the hole after a predetermined number of bounces?

  [Any bounce with an angle of incidence smaller than a right angle determines a trajectory that does not pass through any point of a concentric circle defined by the angle of incidence. At most, one bounce is possible before going into the hole with a trajectory that forms a right angle with the edge of the table.]

- External square billiard: the external square billiard is defined by placing a square on the plane and defining the rebound rule at the edges by extending the trajectory by a length equal to the distance between the starting point and the edge itself. What are the trajectories like?

  [Study of the lattice of "impossible" trajectories and the period of a trajectory with a starting point at any point within the lattice.]

Photos of the posters are available on the web page: `http://matteoacclavio.com/ProgettoHippocampe/HippoBil18.html`

Hippocampe Stage: Automata, languages, and models of computation (February 2018)

This stage on the theme "Automata, languages, and models of computation" was conducted with students from different schools: the Liceo Meucci in Anzio, the Liceo Classico Plauto in Rome, and the Liceo Scientifico Enriques in Ostia. During the stage, different computational models, some of their elementary properties, and classifications were studied.

- Finite state automata: how does a vending machine work? How to solve the problem of three elevators?

  [Definition of finite state automata, use of automata to recognize languages, pushdown automata, automata with linear memory.]

- Formal grammars: definition of language according to Chomsky. Is it possible, by placing restrictions on production rules, to generate assigned languages?

  [Chomsky hierarchy, construction of Type I, II, and III languages.]

- Register machines: how to encode the sum of two integers in a register machine? And multiplication? Can the number of registers be reduced?

  [Construction of a machine for sum, multiplication, multiplication by a fixed integer, encoding any machine with a 3-register machine.]

- Halting problems: is it possible to finish the MIU puzzle? Is it possible to win the Hydra game?

  [Concepts of invariants and termination order.]

- Cellular automata: under what initial conditions is an automaton stable or stabilizes?

  [Study of one-dimensional and two-dimensional automata and definition of stable automata or those that stabilize after a fixed number of states.]

Photos of the posters are available on the web page: `http://matteoacclavio.com/ProgettoHippocampe/HippoLin18.html`

Stage Hippocampe: Infinity (February 2016)

To the students of the 5^a C of the Liceo Classico Montale in Rome, the theme "Infinity" was proposed for the workshop. This workshop aimed to explore different aspects of the concept of infinity and its use in mathematics.

The following tracks were developed:

- The paradoxes of Zeno: Is it true that Achilles will never reach the tortoise?

  [Study of the convergence of geometric series starting from the dichotomy problem];

- The discovery of perspective in art: When drawing in perspective, non-horizontal parallel lines meet at a point called the focus.

  [Some observations on projective geometry];

- Constructive and non-constructive proofs: In Rome, there are at least 2 people with the same number of hairs, and this can be proven without counting the hairs of each person. Transcendental numbers are numbers that are not the root of any polynomial with integer coefficients. How can we prove they exist?

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5 Conclusions and personal observations on the stages conducted in Rome

The Hippocampe stages represent a pedagogical innovation in many respects. Foremost among these, the student discovers the importance of understanding a problem, i.e., describing and analyzing it formally before seeking a solution. This process enhances and helps the student assimilate the final solution found. Mistakes (usually) made during the research process lose their negative connotation and instead contribute to strengthening the final solution, providing the student with the tools to justify their choices.

Moreover, during the stage, the student becomes the protagonist of their own learning. This Copernican revolution in the learning process awakens curiosity and reveals to the student a new, active aspect of study aimed at discovery.

A very important pedagogical phase of the stage is the presentation of one's work to other groups. In this brief presentation, the student faces the necessity of communicating new ideas, which must therefore be formalized as clearly as possible. The significant difference from a regular school oral exam is that no knowledge of the audience can be assumed. Every detail must be analyzed and explained to allow the audience to follow; in this phase, the student becomes the teacher and realizes[5] that transmitting one's discoveries often turns out to be a more difficult task than it seems.

During the poster presentations that conclude the laboratory experience, the teacher/student role reversal reaches its peak with interactions with professors, researchers, and university students from the host department.

In this phase, one observes the effort by students to optimize their communication skills, paying great attention to the formalism developed to interact with experts in the field. The awareness of having acquired sufficient skills to present results to professors and researchers as well as to answer their questions is very positive for the student (also psychologically).

Additionally, while remaining within a learning dynamic, the student steps out of the usual daily model. Some teachers of the classes participating in the stages were surprised by the participation of some students who are usually disinterested in the subject. Similarly, all teachers were positively surprised by the students' ability to dedicate themselves to their topics for the three days of the stage[6].

Finally, during the stage days, the student experiences university as a user and not as a visitor (as happens during regular open days). This leads to an active discovery of the university, spontaneous interactions with university students, and numerous small questions to supervisors about university life and research.

The professors, researchers, and students from the department have always shown interest during the poster sessions, for reasons not only pedagogical but also scientific. Usually, the posters that receive the most attention are those related to problems known for their difficulty or those that present open problems or conjectures formulated by the students.

The feedback from the teachers of the classes has always been very positive from a didactic, disciplinary, and pedagogical point of view. Moreover, they reported an almost totality of positive feedback from the logbooks of the students involved.

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[5]Several students have recounted this experience.

[6]The equivalent hours of a stage are usually covered in about a month of regular classroom teaching (in mathematics).

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