Activity 7

Waves, Fourier series and music

By **André Blais**

Activity developed at
Collège André-Grasset

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If you have any questions or comments, feel free to contact the author at the following address:

ablais@grasset.qc.ca.

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Introduction

The activity consists in using Fourier series as a unifying theme for several sections of the Natural Science program and as an introduction to music. Students must learn, both individually and as part of a team, about Fourier series and the Fourier theorem, using knowledge acquired in mathematics, computer science and physics. They then apply this knowledge to music and the technology of sound reproduction. Using Fourier series, they must also apply their knowledge of electricity to create filters and analyse their effects on sound. The teacher oversees the activity, and offers support and motivation. He or she must bear in mind that the students are learning how to learn.

The students for whom this activity is intended are completing a pure and applied science profile within the Natural Science program. They are enroled in a 45-hour course on the integration of science. This activity, which lasts approximately five weeks, was offered for the first time in the winter 2001 semester to two groups of 24 students, on average. The size of the group should not exceed this number. A considerable portion of the work is done in the physics and computer science laboratories. The activity leads to an examination the week after students submit their assignment. The activity is worth 35% of the overall course mark. Three other activities make up the course: the application of mathematics in physics, the construction of a radio and a PowerPoint presentation on a scientific topic.

The teacher can illustrate the analysis or synthesis using a synthesizer and an oscilloscope and use musical instruments to make the demonstration more colourful. Often, the teacher or some of the students play musical instruments.

Educational objectives

The aim of this activity is to improve the students' integration of knowledge, especially the use of mathematics in science, and experimental applications. The objective is also to help the students develop autonomy and self-assurance when it comes to solving new problems. The students will also be given the chance to work in teams and discover the important role that peers play in learning and research.

This activity is part of a course that rounds out the Natural Science program. It enables students to use mathematics, computer science and physics to illustrate part of the vast knowledge that they have acquired through the program. In more traditional courses, students do not always have the opportunity to expand their knowledge and to extend this knowledge to situations outside the classroom or the laboratory. They do not often have the chance to establish links between their courses and the world around them. This activity enables students to transfer what they have learned in the computer science laboratory to their differential and integral calculus courses and their physics courses on waves and electricity. Moreover, the activity makes it easier to analyze a musical note created by means of various instruments (e.g. an electronic synthesizer) and to understand the technology of music reproduction. This diversity is very exciting for students.

Relationship with the program

The following are the general aims of the Natural Science program dealt with in this activity.

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Specific objectives

- **To apply the scientific method.**

  In the activities conducted in the physics laboratory, the students must make several observations and collect data, on the basis of which they must formulate and verify their hypotheses. In certain cases, they must perform equipment setups and use measuring instruments correctly. They must deduce results and interpret them correctly. This is particularly the case when studying filters.

- **To use appropriate information processing technologies.**

  The students must use the symbolic language Maple and a word processor. Maple enables students to do a demonstration of the Fourier synthesis and to animate the simulation. They present the work on paper and e-mail it to the teacher.

- **To reason scientifically.**

  The students must present the Fourier, theorem, analysis and synthesis. They must search through the appropriate documentation and find ideas that they can express clearly and logically. Rigorous thinking is needed in the laboratory in order to achieve the desired objectives.

- **To communicate clearly and precisely.**

  In order to structure their work, students must first express themselves clearly within their team. They must read several texts and then write their presentation clearly and logically.

- **To learn autonomously.**

  The students must demonstrate considerable autonomy. They will not be given any courses or plans. They must find their own documentation and organize it logically, planning their work in order to carry out their assigned project. They must conduct their own second experiment on filters in the physics laboratory.

- **To work in a team.**

  All the work is done in teams of three. Students must establish good communication with team members to ensure that the team works well together. Students can adopt one of several roles within the team: one member can act as team leader, another can act as key cooperator and yet another can encourage members on the verge of a depression and set them on the right track. Everyone must learn to work as a team.

- **To establish links between science, technology and a changing society.**

  Using several mathematics, physics and computer science tools, the students establish links between science and technology. The topic also involves music, an omnipresent art form in our society. Technology is presented as a tool for a society that appreciates this art form in its daily surroundings. The students analyze the production of some musical instruments, including the synthesizer. They also study the digitization of sound (CD, computer, etc.).

- **To adopt attitudes conducive to scientific discovery.**

  This project helps students develop attitudes and qualities that are useful for scientists. Although the problem may at first appear enormous, it is important for students to persevere. Students may not immediately find what they are looking for and must sustain their efforts. They must do a demonstration of Fourier synthesis using Maple and therefore demonstrate creativity. Since working in teams is not always easy, students must be flexible and cooperative. They must choose from among a multitude of information collected and develop their critical thinking skills.

- **To handle new situations on the basis of acquired knowledge.**

  This objective is central to the project. The following are a few examples:

  The students draw information on derivatives, integrals and series from their mathematics courses; they take the information they need on waves and RC circuits from their physics courses; they use what they learned on the Internet, as well as from Maple and Word. They develop mathematical tools with the Fourier series, a greater understanding of waves with the Fourier analysis, physics tools with the RC filters and computer tools with the digitization of analog values. They develop a better understanding of musical instruments and learn how a synthesizer works.

General objectives

From a general standpoint, the project requires that students submit a structured and well-written report. Having a command of the language will enable students to express their ideas and arguments clearly.

The students must find documents that will enable them to understand the subject. Since most of the documentation is in English, students must have a solid command of the language. They will note its importance in the fields of science and technology.

The project also opens students up to the world of music, an area that is vastly different from science. The students will be able to observe the links between art and science.

Relevance of the activity

This activity is part of a course dedicated to integrating mathematics and science and successfully targets several general aims of the Natural Science program.

It highlights several links between the courses offered within the program; the students use the following concepts and tools:

- Derivatives, integrals and series (*Differential and integral calculus*)
- Waves (*Waves, optics and modern physics*)
- Filter circuits (RC circuits, *Electricity and magnetism*)
- Computer science: programming (Maple symbolic language), Internet, word processing, e-mail, etc.

Elements of the entry profile

The students taking part in this project must have completed the NYA, NYB and NYC mathematics courses, and the NYA and NYB physics courses. Moreover, they must have completed or be enroled in *Mathematics 303* (*Differential and integral calculus III*) and NYC physics.

Objectives of the exit profile

The activity combines several elements of the exit profile for pure and applied sciences. The students must:

- Develop a sound command of differential and integral calculus as they apply to science;
- Develop a sound command of the basic elements of a symbolic programming language (Maple);
- Demonstrate self-assurance and autonomy in the laboratory.

Educational support and instructions to students

The teacher acts as a project guide and manager by providing the students with various documents: Students' guide (Appendix E.1), including Low-pass RC filter, laboratory instructions and protocol, instructions for completing a logbook and interesting Web sites.

The teacher must therefore have a command of the following concepts and tools: differential and integral calculus, RC circuits and filters, sound waves, Fourier series, and Maple. He or she is responsible for creating teams and preparing computer science and physics laboratory equipment.

The activity takes approximately six hours per week over a five-week period (course 0-3-3). The teacher should be available three hours per week. The students do approximately three additional hours of individual work. We created teams of three. The teams were formed by choosing one student from each of three groups (A, B and C), so that each team had one strong student (group A), one average student (group B) and one weaker student (group C). Students were classified on the basis of their marks in the prerequisite mathematics and physics courses. The students were not aware of how the groups were formed.

The teacher prepares sample reference lists, essentially Web sites, and posts it on the college's computer network. He or she must ensure that the computer science and physics laboratory equipment is available whenever necessary.

Description of material

The students must have access to a computer with an Internet connection, on which a word-processing program and Maple (or an equivalent) have been installed. The physics laboratory must be equipped with a audio wave generator, an oscilloscope, resistors and common capacitors.

Students' materials

Appendix E.1: Students' guide - project: Waves, Fourier series and music

Teacher's materials

Appendix P.1: Second examination

Appendix P.2: Summary of results of a mini survey of students

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