Ciência: gaining a feeling for sciences

To cite this article: Marcos Henrique Abreu de Oliveira and Robert Fischer 2017 Phys. Educ. 52 025011

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1. Hands-on experiments at Brazilian schools

When Richard P Feynman, an enthusiastic physics teacher, visited Brazil in 1951, he saw to his delight ‘elementary school kids in bookstores, buying physics books’ [1]. Yet after teaching a semester at a university in Rio de Janeiro, he came to the conclusion that ‘no science is being taught in Brazil’. In his memoirs, he wrote: ‘after a lot of investigation, I finally figured out that the students had memorized everything, but they did not know what anything meant’. While students could ‘recite, word for word’ even advanced physics, they were not able to relate them to real-world problems, nor could they apply them in simple experiments. Feynman addressed the issue in a talk he gave at the end of the semester: ‘finally, I said that I could not see how anyone could be educated by this self-propagating system in which people pass exams, and teach others to pass exams, but nobody knows anything’ [1].

In the 65 years since Feynman’s visit, Brazil’s educational system has made significant improvements. Today, educational institutions put more emphasis on understanding and experimental evidence. Efforts to set the discussion of natural phenomena in a meaningful and relevant context, have begun to transform curricula, school books and started to arrive in class rooms. Hands-on experiments, however, as Feynman had advocated them, are still rarely seen at Brazilian schools. Such student-centred activities as depicted in figure 1, in which small groups explore natural phenomena with their own hands and minds, are not merely applied ‘for fun’, or to raise young peoples interest in sciences, but make crucial contributions to the learners’ development by fostering skills and evidence-based intellectual autonomy. To understand why teachers in Brazil hesitate to make use of this proven didactic method [2, 3], it is important to look at the local situation and difficulties faced by teachers...
when experimenting in class. Over several years, the project Ciênciação has studied this learning environment with regards to educational policies, teacher training and day-to-day teaching practice at primary and secondary schools, before developing an approach to address common obstacles and win over teachers for hands-on experiments in class.

Already in 1997, the Ministry of Education published in its national curriculum [4] the recommendation: ‘an experiment becomes more relevant to students when they participate in planning it, conduct it themselves, handle the equipment themselves, and then discuss the results’. Few teachers followed the advice at the time. In recent years, however, educational policies increasingly stress the importance of fostering skills, like critical and analytic thinking, team work and effective communication [5], which are closely related to hands-on experiments [3, 6]. As a case in point, the ENEM, a nationwide entrance exam for public universities, has been remodelled to test skills and competences. Memorised fact knowledge still plays an important role, but answering science questions now requires real understanding. Consequently, teachers need to adapt their syllabus and didactic methods if they want to prepare their students for this important exam.

After decades in this ‘self-propagating system’ of being focused on memorised fact knowledge, this is not an easy change for teachers to make. Few of them have ever experienced student-centred or skill fostering science education themselves. University courses on pedagogy offer little orientation beyond theoretical discussions, since future teachers are usually prepared in classical ex-cathedra lectures [7, 8]. Most educators will readily agree that memorised fact knowledge alone is insufficient to prepare students for lucrative careers or fulfilling lives with informed social participation. And yet, many hesitate to deviate from their familiar ‘chalk talk’ in order to include hands-on experiments. Commonly cited reasons can be summarised as follows:

- **Lack of time:** like in most educational systems, Brazilian science teachers have to squeeze an overloaded curriculum into a small time frame. To give a quantitative example, students graduating in 2016 from the secondary technical course at IFAL, an institution run by the federal government, should have attended 267 h of physics over 3 years. Due to exams and administrative tasks, such as verifying the presence of each student, they effectively were offered less than 200 h of physics, without taking into account sickness related absence and frequent strikes at educational institutions. Thus, in less than 200h, teachers have to cover the complete content

![Figure 1. Hands-on experiment not only raise student’s interest in sciences, but are an essential component in skill fostering science education [6].](image-url)
of classical physics, including mechanics, optics, thermodynamics, and electromagnetism. Since the traditional teacher-centred approach allows to advance faster through the material, it is understandable that under these conditions teachers see little room for time consuming student activities like hands-on experiments.

- **Insecurity and lack of training:** even veteran teachers may feel uncomfortable overseeing a class of autonomously experimenting groups—especially, if they have never done so before. The unfamiliar situation requires different classroom management skills. Moreover, when students are truly engaged in an experiment, questions will arise, which the teacher may not be able to answer. While admitting not to know the answer is essential for scientific progress, it is perceived at odds with the teacher’s cultural role as authority. For teachers with limited content knowledge, it is therefore easier to align their content closely with textbooks and concentrate on mathematical exercises: according to the official 2011 school census in Alagoas, a state in Brazil’s poorer North-East, more mathematicians were teaching physics than actual physicists. Only 20% of the physics classes at public schools were given by teachers with (or at the time pursuing) a tertiary degree in physics [9]. Similar problems were reported in other Brazilian states [8].

- **Lack of resources and infrastructure:** this is often more an imaginary problem than a real one. Scientific experiments are believed to require sophisticated tools and specialised laboratories. In order to protect such expensive equipment from accidents, students are then only allowed to operate them following detailed step-by-step instructions, instead of following their scientific curiosity. Teachers looking for alternatives will find a variety of online sources proposing experiments with household materials. These experiments, however, are usually designed for entertainment, not for teaching. Placing the teacher in the role of a ‘magician’, they value impressive visual or acoustic effects above clarity, and may need time consuming preparation. Even if they are considered safe when conducted under adult supervision, this might no longer hold true in a setting where the adult has to keep an eye on 40–50 experimenting students at once.
Another reason, why science teachers tend not to include hands-on experiment in their lessons, is the local custom to separate experimental activities from theory lessons. In particular at private schools, laboratory work is often conducted under the supervision of specialised educators and only loosely aligned with the respective theoretical content taught by the physics or chemistry teacher. It might take weeks, before students conducting an experiment will discuss with their teacher which physical phenomena or chemical reaction had caused the observed effects. Or they might have talked about an effect weeks before getting to see it.

2. Integrating hands-on research activities in day-to-day teaching

An initiative like Ciência will not be able to remove all these obstacles, but it can help teachers to overcome them. In practice, this means to convince teachers that short experiments—which may take just a couple of minutes or even seconds to conduct—can smoothly transit to productive class discussions, in which students simultaneously advance their fact knowledge, deepen their understanding and foster their scientific skills [2]. This is based on the assumption that teachers who made positive experiences with this approach, will adapt it to their personal teaching style and make it part of their day-to-day teaching practice.

Teacher training programs are an effective method to convey this idea, but they are limited in their reach by human and financial resources. In order to provide the material to a wider audience, the Ciência project has therefore been implemented as an online repository of open educational resources. Hands-on experiments are published at the repository in Portuguese, Spanish and English, so that they are accessible for teachers in all of Latin America. These resources are not only open in the sense that they are freely available under a Creative Commons license, but also in the sense that anyone can contribute by submitting her or his own experiment (which will be peer-reviewed). Professional educators need such editorial freedom to adapt course material to their students’ needs. By sharing the content they create in the process, they shape Ciência’s development and help it adjust dynamically to the community’s interests [10].

Published experiments are designed to easily integrate in regular lessons in normal class rooms. Of primary concern is thereby the time and effort required to prepare and conduct an experiment. The less time a teacher has to invest, the more he will be open to trying a new methodology. Well-known experiments have therefore been modified to minimise their cost in teaching time, which often goes hand in hand with simplifying them.

In many cases, this means working with qualitative results obtained by direct observations, instead of quantitative measurements (see e.g. figure 2). Besides reducing the activity’s complexity, the concentration on qualitative results also serves the actual purpose of Ciência.
experiments, namely to engage students in an evidence-based discussion about the interpretation of their observations. To embed experiments in a meaningful learning context, each one is built around a specific student research task. The task’s questions or challenges provide a clear orientation, what the student is supposed to find out and learn from the experiment. And yet, at times, even apparently simple questions, like ‘Are the two ends of a magnet different?’, may lead to sprawling class discussions, challenging teachers to find the fine line between restraining the discussion and allowing students to develop their ideas. Mastering this balance is of great importance for the overall effectiveness and quality of the learning experience. To avoid frustration for both students and teachers, Ciênsação therefore offers ‘guiding questions’, which break down a student research task in smaller steps, and, when used in a Socratic style, can advance the discussion in the intended direction. Furthermore, these questions can serve teachers to make a smooth transition from an experiment to the respective theoretical background without losing the motivational momentum of the activity.

Ciênsação experiments also include a concise explanation of the observed phenomena, which are meant as a starting point for more detailed investigations. The intention is not to replace textbooks, but to reduce preparation time, and to help less experienced teachers in leading the class discussion with confidence.

Materials used in such hands-on experiments need to be selected with great care. No responsible teachers will accept activities which could put their students’ health at risk, nor can they be expected to buy expensive equipment, which their school is unable to provide. Consequently, Ciênsação experiments need to rely on safe and easily accessible low-cost materials. Wherever possible, these are household items, ideally objects that students have at hand, like books, pencils or coins (figure 3). On one hand, simple, generic and versatile materials have the advantage of allowing students to experiment more freely, and to follow their scientific curiosity in unforeseen directions [11]. On the other hand, variations in the employed equipment can cause confusion among students, and setups which require much tinkering distract students’ attention from the actual phenomena towards the preparations—besides costing teaching time. Before publishing an experiment at the repository, it is therefore tested with a variety of set-ups to ensure safety and to find the right balance between simplicity, flexibility and material costs.

3. Gaining a feeling for sciences

Beyond just making is easy for teachers to integrate them in regular teaching, Ciênsação experiments are specifically designed to foster scientific skills, such as critical thinking, evidence based argumentation and experimental inquiry. Moreover, they are intended to let students gain a feeling for sciences, which gave the project its name: Ciênsação is a neologism joining science (Portuguese: ciência) and feeling (Portuguese: sensação; the English website is named accordingly as sciensation.org).

Obviously, responsible individuals should never let subjective feelings interfere when evaluating scientific evidence. However, the common association of science with ‘hard’ facts often (unintentionally) implies that science is primarily a collection of known facts. This reduces science, which is actually less about facts than about the skill, methodology and joy of finding them, to just a subset of its results. Equally, one could reduce the concept of art to ‘things found in museums’.

The research tasks, around which Ciênsação experiments are built, invite students to actively do science, instead of merely reproducing known results and confirming textbook claims. Giving students a few minutes to pursue such a task autonomously in small groups, allows them not only to experience the excitement of discovery, but also to experience science as a creative activity, as a craft they can master, rather than the privilege of an elite called ‘scientists’.

The idea of gaining a feeling for sciences also extends to acquiring an intuitive understanding of physical or chemical systems and their behaviour. It makes a great cognitive difference to either calculate the resonance frequency of a theoretical mass-spring system, or to make a weight oscillate on a spring held by one’s own hand [12]. Physical laws often make more ‘sense’ to a learner, if they can be related to a personal haptic, visual and acoustic sensation.

Similarly, students can learn important lessons about the nature of science when
discovering contradictions between textbooks and their own experimental results. Errors in some school books—such as claiming that different tastes are perceived in distinct regions on the tongue (figure 4) [13], or depicting the magnetic north pole on the northern hemisphere [14]—provide valuable opportunities to teach the importance of searching scientific evidence instead of uncritically relying on authorities. Counter-intuitive observations, like the attraction of equal magnetic poles if a coin is placed between them [15], are often more motivating to hone students’ research skills than experiments with predictable outcome. Some Ciênciação experiments even discuss the scientific method itself [16]. To show that a majority opinion does not equal scientific evidence, one experiment asks students to observe the movement of laser speckles on a wall while moving their heads [17]. Whether the speckle pattern moves in the same or the opposite direction as their head, depends on each observer’s individual eyesight (observers with hyperopia will see the speckle move in the direction of the head movement, while myopic observers will see them moving in the opposite direction). Nonetheless, the teacher—temporarily deceiving her students—pressures the class to decide on one direction and contests diverting opinions, before revealing the true nature of the experiment. If some students started to doubt their own observation or even gave in to peer pressure, the whole class gets to know a critical pitfall of the scientific endeavour.

4. Impact

Whether the project Ciênciação can meet the ambitious expectations set in it, is currently tested in teacher training courses at the Federal University of Paraná (Brazil) and the Federal University of Fronteira Sul (Santa Catarina, Brazil). A recent workshop, held at the Federal University of Rio Grande do Sul, brought together educational researchers, science teachers and students to discuss how Ciênciação can be extended to reach more teachers, and allow them to interact more efficiently with the platform and each other.

Meanwhile, experiments in the online repository are read by teachers from all over the world, and comments of appreciation were received from countries as diverse as Ghana and Germany. An offline version of the experiments is distributed on memory sticks to teachers on Fiji and Solomon Islands, who have limited access to the internet. This encouraging feedback and a growing number of online visitors indicate that the first steps of the Ciênciação project indeed contribute to a culture of short hands-on experiments and skill-fostering science education—well beyond the intended audience of teachers in Latin America.

References


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[12] Experiment: Mechanical resonance (www.sciensation.org/hands-on_experiments/e5072p_mechanicalResonance.html)

[13] Experiment: The myth of the tongue map (www.sciensation.org/hands-on_experiments/e5004b_tongueMap.html)

[14] Experiment: Where is the magnetic north pole? (www.sciensation.org/hands-on_experiments/e5100pg_earthMagneticPole.html)


[16] Experiment: Guess my rule—like a scientist (www.sciensation.org/hands-on_experiments/e5035m_guessMyRule.html)

[17] Experiment: Believe your eyes, do not be deceived by ‘public opinion’ (www.sciensation.org/hands-on_experiments/e5043p_laserVision.html)

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