VIRTUAL AND PHYSICAL RESOURCES: A CASE OF SYNERGY IN STUDYING TIDES AND ROTATION

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Abstract

Because of their very nature, virtual models are usually more abstract than physical ones. Physical models may facilitate the use of virtual models, by making links to physical world. Tides come into play in a wide variety of curricular scopes, but they are not easy to understand, both in basic education and in initial teacher training. In addition to this, simple physical classroom experiments about tides are not easy to conceive, and they may even be misleading. In a previous work, one of the authors developed a virtual model: a computer simulation of tides. It reveled to be useful, although not covering some students' learning needs: it was too abstract and mathematical for most of the students. There was a need of complementing the virtual model with material ones ("added reality"). Two physical devices were then developed: a "physical model for tides" and a "physical model of grass growing in artificial gravity". The two physical models proved to be feasible and useful. The set of three models revealed to create synergies in learning.
Key words: *virtual models, physical models, tides, rotation*.

Introduction

Ocean tides were crucial in the transition of life from oceans to land and they are crucial in the maintenance of life and of the whole planet. They are visible near the sea, and fishermen's activities depend on them. They play an important role in oceans' currents and dissipate kinetic energy into heat. Tides in the lithosphere also dissipate kinetic energy into heat (they may even drive earthquakes), and they must be taken into account in large research plants such as the CERN (acceleration rings are deformed). The first direct observation of an extraterrestrial collision of solar system objects, that of the comet Shoemaker-Levy 9 in Jupiter in 1994, also allowed the observation of the comet broking apart by tidal effect before colliding. In the earth's atmosphere, tides play an important role in air currents and other climate factors. There are electric production plants based on oceans' tides. Tides in our planet are driven by the moon and by the sun. Neap and spring tides are related to moon phases. Agricultural rhythms are led by the sun and the moon positions since the early days of mankind.

Thus, this theme comes into play in a wide variety of curricular scopes: life evolution, agriculture, fishing, climate, leisure, water, energy, environment, sustainability, solar system and many others. Nevertheless, understanding tides is not easy, neither for students and teachers in basic and secondary education, nor in initial teacher training (Arons, 1990; Viennot, 1996).

Understanding tides requires some insight (even if at a non-analytical, semi-quantitative and elementary level) into a physics conceptual field that includes: force as an interaction; gravitational field and force; mass and weight; Newton's laws of Dynamics and law of Gravitation; inertial and non-inertial reference frames; inertial forces; the dynamics of the system Sun – Earth – Moon and the dynamics of the subsystems Sun – Earth and Earth – Moon; how these dynamics generate tides and how these influence those dynamics; the existence of two high and low tides and of neap and spring tides; free fall; weightlessness and artificial gravity. This conceptual field, even adapted to the corresponding age levels, is hard to most students, from basic to higher education.

As said before, understanding tides is not easy. Most students easily understand — rather, they think they understand — the occurrence of a tidal bulge on a planet on its nearest zone in relation to the gravitational source considered, "because this pulls it"; but explaining the tidal bulge on the farther side of the planet is "another matter" (how can a pull to a centre originate a bulge outwards from it?).

In addition, simple physical classroom experiments about tides are not easy to conceive and perform, and they may even be misleading, because the gravitational force is distributed on the body and varies with distance.

Thus, one of the authors tried another approach: he developed a virtual model for spreadsheet simulations (Silva, 1998). It reveled to be useful, although not covering some students' learning needs: it was too abstract and mathematical for most students. There was a need of complementing the virtual model with material ones ("added reality").

We describe this virtual model, two physical models recently developed and the synergy between the three.

Problem and Methods

Because of their very nature, virtual models usually are more abstract than physical models. Physical models may facilitate the use of virtual models, creating a link between them and reality. Two of the authors had already worked on problems related to "added reality" in complementing "virtual models".

One of the authors created and used virtual models (Silva (1994 a); Silva, 1995) in the study of electrical circuits. Those models were used along with physical experiments. The same author used similar approaches in studying Archimedes's law (Silva, 1998) and also inertia and non-inertial forces (Silva, 1994 b)).

Another of the authors (Silva et al., 1998) used physical maps to scaffold children in linking real soundscapes in a natural park to the virtual soundscapes of a multimedia application based on a virtual model of the same park. This same author (Silva et al., 2009; Gomes et al., 2007) used digital cameras, paper photos, drawings and maps as complementary tools to virtual globes in representing reality in elementary schools.

In the case reported here, there was a need for complementing the virtual model referred in the Introduction with material ones to be used "hands-on" (in the literal sense). This is the problem that we deal with in this report.

The opportunity to construct such physical models emerged on the present school-year (2009-10): one PhD student and three MSc teacher students who were working on related topics. The three MSc students conceived and implemented two physical devices: a "physical model for tides" and "grass growing in artificial gravity". Both devices have been developed in two distinct and cooperating environments: the MSc classes; and the elementary school classes. The tides model has been used by one MSc student teacher with a group of twelve students with ages between 10 and 15 years-old. It was an informal group of students who were attending scientific and artistic activities at our Institution (ESE-IPPorto) after the end of their school year. The grass growing activity has been explored by another MSc student teacher in a class of its own, in which she was teaching Natural Sciences to 28 students aged 11 years-old (in average).

Thus, the work presented in this paper is based on the previous research work of two of the authors using physical models to overcome the abstraction and complexity of virtual models, and it has the following methodological characteristics: i) the two physical models were developed as projects of experimental nature; ii) these projects were developed in action-research processes; iii) one of the physical models is strictly about tides and the other is related to this topic by the criss-crossing of central components of the conceptual field involved; iv) the virtual model and the two physical models were explored in a complementary way.

It must also be stressed that, in the MSc class, a special attention has been paid by the teacher (one of the authors of this paper) to central aspects of teacher mediation, as described in Lopes et al (2008), namely in relation to the dimension "the work really demanded from students": every task with educational interest must give to students an acceptable control over their activity and they must know exactly what they need to do to achieve an answer or solution; an it is also essential that students have access to the contextual meaning of the task.

Overall, this is a case report.

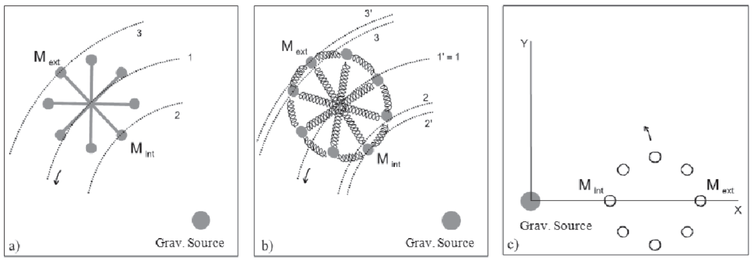

Figure 1. a) Ideally rigid body for reference; b) Model body made of some discrete masses connected by damped oscillators; c) Initial position.

Virtual and Physical Models [1]

Tides: a virtual model body and spreadsheet simulations

Basic to the explanation of tides in earth is the fact that the moon orbits the earth but the earth also orbits the moon. (Withers, 1993; Feynman et al., 1966, p. 7-4; Bueche, 1981, p. 518; Silva, 1995). More precisely, both go around their common Centre of Mass (CM).

The basic equation is $\vec{F}^{external} = M_{syst}\,\vec{a}_{CM}$, where M_{syst} is the total mass of the system; $F^{external}$ is the sum of all external forces acting on it; and a_{CM} is the acceleration of its CM. Although lunar generated tides have an intensity that is related to solar generated tides in the ratio 11/5, it is easier to visualize and to sketch a body going around a point located outside it (as in the earth-sun system) than going around a point located inside it (the CM of the earth-moon system is located roughly at one quarter of the earth's radius below the earth's surface). The focus is this: *how two bulges are generated in a body that is orbiting a source of gravitational field.*

As well known (Feynman et al., 1966; Hood, 1992), in the Newton's law $\vec{F} = m\,\vec{a}$ the

[1] The complete spreadsheet file for tides, as well as photos and videos related to the two physical devices, are available from the authors upon request.

left is about the characteristics of forces involved, and the right side is the kinetic one. For a body orbiting a gravity source, we may write: $G\,M\,m/r^2 = m\,v^2/r$; $G\,M/r = v^2$.

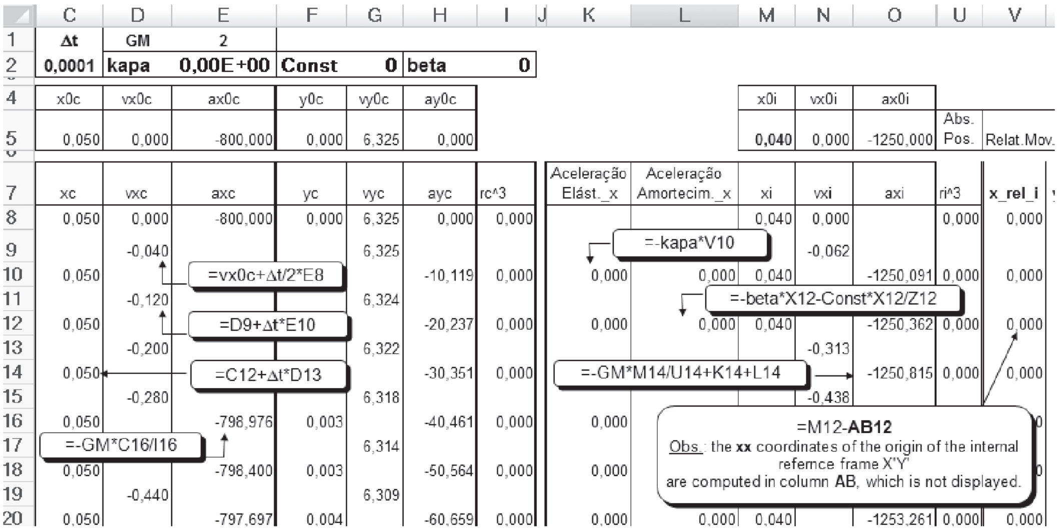

Figure 2. This is a partial view of the of the spreadsheet model for numerical integration of Newton's equation. The columns at left (where "c" appears as in "x0c"), refer to the CM of the model body. The columns for M_{ext}, as well as some columns for the y components of M_{int}, are not shown. The external force on the model body is due to gravity. The internal forces are considered in $\vec{F} = -kappa\,(\Delta\vec{r}_{rel}) - beta\,(\vec{v}_{rel}) - Const\,\vec{v}_{rel}/|\vec{v}_{rel}|$ **(elastic force and two types of frictional force). The user inputs values for these three constants and also for initial conditions of the movement. The numerical integration requires about 50 columns and 500 lines. All the lines from 10 on contain the same formulae as lines 8 and 9. The fundamental formulae are represented in auxiliary labels.**

The earth is not a concentrated, ideal "particle" of matter or an ideally rigid body. The part of the earth *closer* to the moon will be under a gravitational attraction that is *greater* than the corresponding value at the earth's own CM. As a consequence, that part tends to move *closer* to the moon (like the inner planets in the solar system). The part of the earth at a *longer* distance from the moon will be under the effect of a weaker force and tends to move *away* (like the outer planets in the solar system). Thus, the earth is under a tension that tends to stretch. This is the origin of tidal forces, both on our planet and on the moon. The earth and the moon do not break apart because there are internal coupling forces that maintain their cohesion. There are also friction forces and heat generation and loss of mechanical energy.

Δt	GM	2				
0.0001	kapa	1.00E+05	Const	80	beta	800

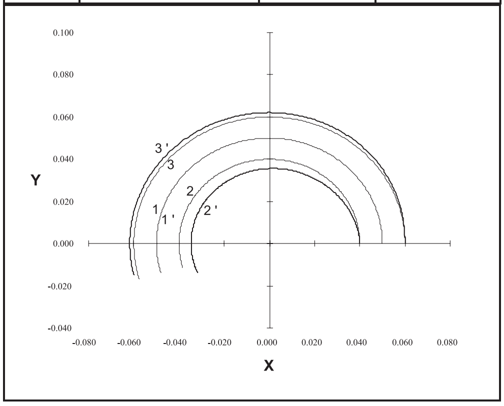

Figure 3. 2' goes closer to, and 3' goes farther from, the origin.

Δt	GM	2				
0.0001	kappa	0.00E+00	Const	0	beta	0

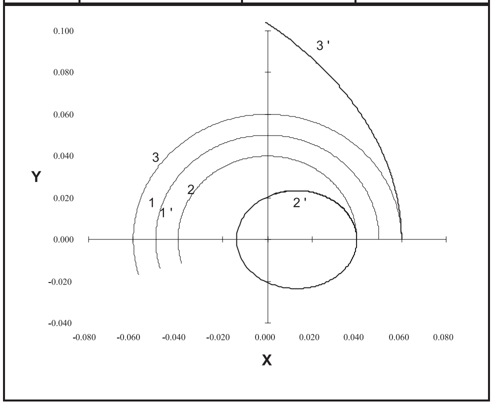

Figure 4. In this case, the elastic body explodes: M_{int} and M_{ext} become independent.

We consider the model body presented in Figure 1. The corresponding codified spreadsheet model is presented in Figure 2. It allows simulating by changing input values and representing the trajectories graphically. As Feynman et al (1966), arbitrary units are used, and the integration of Newton's equations is be made using the half-step modification of the Euler method. We consider here the gravity source as a highly concentrated mass with a value much greater than the mass of the orbiting body. Thus, the system's CM can be considered as being coincident with the gravity source and located at the origin of an X-Y co-ordinate system at rest. Both bodies in Figure 1 are idealized as two-dimensional. When at rest and with no forces applied, both bodies are circularly shaped. Both are thrown in the position represented in Figure 1 c**)**. Our focus here is on the movements of M_{int} and M_{ext} of the body represented in Figure 1 b**)**: two situations are shown in Figures 3 and 4.

A physical model for tides: construction, use and results

One of the authors, a MSc teacher student, worked on conceiving and constructing a physical model for tides. The model should be cheap and of easy construction and use, even by children. It also should be scientifically acceptable as a tool to help the understanding of a central issue about tides: how and why there are two bulges and, in particular, how and why there is a bulge away from the centre although all the forces are directed into it.

The experimental device is shown in Figure 5. It is made of a rubber ring and two strings with adequate elasticity constants attached to it, together with pencils (not visible in the Figures). The pencils draw circle lines on a paper placed on the ground when the ring is made to rotate by an experimenter. See Figure 6.

Figure 5. The physical model for tides (at rest).

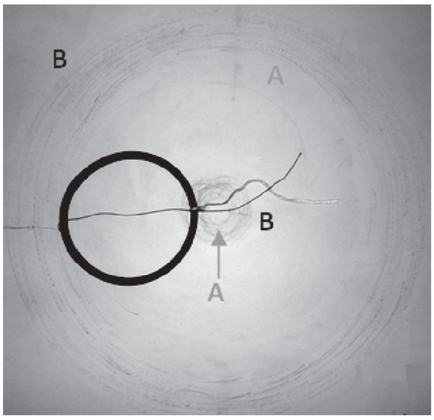

Figure 6. When the experimenter pulls both strings together, the lines A were drawn on the paper. When pulling only the white string, the lines B were drawn.

The model does not replicate the gravitational forces or its differential variation. These and other limitations of the model must be discussed with students, at a conceptual level adequate to their age and previous knowledge. The central feature that the model illustrates is this: there are two bulges, because the ring is made to orbit around a point (in fact, the little central zone where the experimenter hand slightly moves). In particular, after making the experiment the students have no doubt about these crucial conceptual feature: the outer part of the ring is deformed outwards, although the force acting on it is inwards; there are no forces pulling any part of the ring outwards.

The students (10 to 15 years old) were receptive to this model. Essentially, they tried and realized why there is a high tide on the farthest side of the moon despite a force that "push it" in its direction (represented by the dark string).

The physical model was also presented to the students of the MSc class (16 teachers aged between 28 and 40 years-old), which considered it useful and expressed interest in use it in their classrooms to explain to their students, in a simple manner, the phenomenon of tides.

Grass growing in a rotating container: construction, use and results

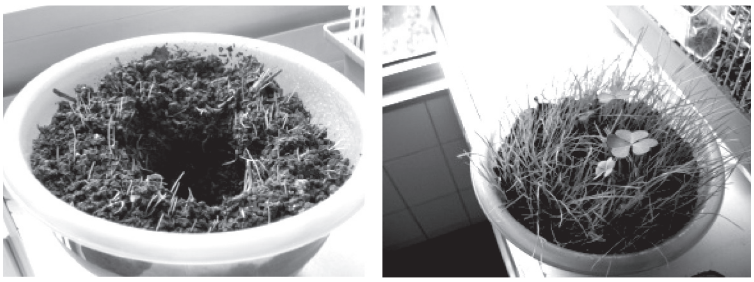

Figure 7. Stationery situation.

Two weeks after seeding (left) and four weeks after (right). At right, it can be seen that the grass located more at right in the container grew up slightly inclined to the right as a consequence of phototropism: the light was coming mainly from a window located in that direction.

This has been discussed and considered as a "side-effect" in the context of these activities.

In this knowledge domain it is of critical conceptual importance to understand that — in an inertial reference frame, where there are no centrifugal or Coriolis forces — there are no forces pulling any part of the ring outwards in the tides model. This is very important in learning about tides and also about other related phenomena.

Two of the MSc teacher students asked to their eleven years old students how seeded grass would grow in a rotating container. All of them answered that the grass would emerge from the soil and then grow inclined outwards. Those two authors then asked the same questions to her colleagues of an MSc class. All of them answered the same way: outward bending. All these answers are related to the belief that a centrifugal force is a real force, an interaction.

The gravitropism / geotropism, is the "response" of plants' organs to the gravitational force. The aerial part of a plant grows in the opposite direction to the gravitational force (negative geotropism) and the roots in this direction (positive geotropism). In Figure 7, the gravitational force is vertical and "down", and the lift due to the ground is vertical and "up". This situation constitutes a reference control for what follows.

The bodies will have great importance in plant life-support systems in space. But how do they know where to grow, there is no "top" and "low" in weightlessness? For them and the astronauts will be helpful to create an "artificial gravity". We've conceived a classroom activity from which we don't know any previous description.

We present the assembly in Figure 8: interconnected with the motor shaft of a fan, we have put a container with soil and grass seeds. The motor was put in motion. The results obtained are shown in Figure 9.

When in rotation, grass grew towards $\overrightarrow{FN}$ $\overrightarrow{FN}$ in Figure 10. The resulting force $\overrightarrow{FC}$ $\overrightarrow{FC}$ is the sum of $\overrightarrow{FN}\overrightarrow{FN}$ (due to the container, or "ground ") and $\overrightarrow{FG}\overrightarrow{FG}$ (gravitational force).

(In the Non-Inertial Reference Frame associated to the container, in addition to $\overrightarrow{FN}$ $\overrightarrow{FN}$ and $\overrightarrow{FG}\overrightarrow{FG}$, there is a centrifugal force, and the resulting force, acceleration and speed have a null norm)

Both in the seed and plant, the sustention force due to the "ground" is $\overrightarrow{FN}\overrightarrow{FN}$. It is as if the gravitational field was perpendicular to the "ground" and it was compressed against it: perpendicularly and out.

The presence of auxin in plants causes the growth of its aerial parts towards $\overrightarrow{FN}$ $\overrightarrow{FN}$: Figures 7, 9 and 10.

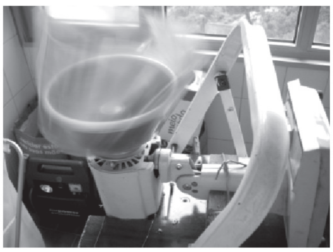

Figure 8. Physical model of artificial gravity. Because the container is rotating, the transparent protection put around it appears with a fuzzy aspect in the photo.

Figure 9. **Two weeks after seeding (up) and four weeks after (bottom).**

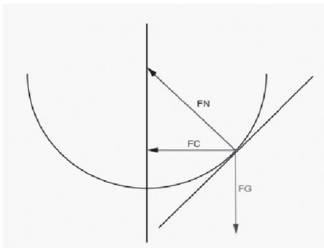

Figure 10. **Inertial reference frame: rotation and forces.**

In class, with students averaging 11 years-old, it has been referred the International Space Station. Students were told to build with didactic materials a Space Station: Figure 11. It was told to them that the Station should have a rotating module.

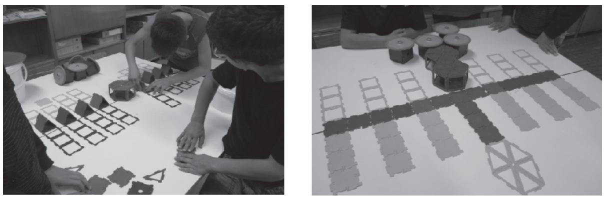

Figure 11. **Construction of the ISS.**

The teacher then asked them to draw how a plant would grow in earth and in the space station. Four typical drawings are shown in Figure 12. All students draw the plant growing up when at rest, as illustrated by the drawing at left. For the case where the plant was growing up in the rotating module of the space station, some students could not answer, but most of them considered that the plants would grow “out”, away from the centre of rotation, as illustrated in the drawing at right. This is consistent with the answers reported at the beginning of this section (related to incorrect conceptions about centrifugal forces).

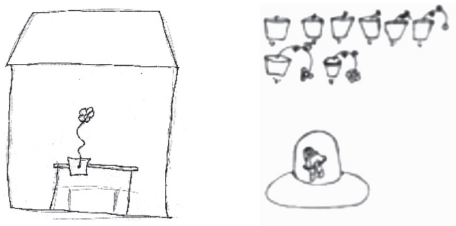

Figure 12. Drawings of the growth of a plant: at rest (left); in a rotating module of a space station (right).

Afterwards, the teacher and the students made the device and the experiments presented in Figures 7, 8, 9 and 10. A detailed description of these activities is beyond the scope of this report. We refer a central feature: students were really surprised by the fact that the grass did not grow outwards and, instead, clearly grew in the opposite direction (inclined into the centre of rotation).

At that time, the teacher asked students to refer everyday activities that could allow us to understand the influence of gravity on a body in a rotating movement and which would facilitate them to explain the reason for the different growth of the grass in both recipients, because for most students, that which was submitted to the rotating movement would grow out, figure 10. In a sheet, they reported the day-to-day situation. We refer three of them (translated into English): a) «When we ride a bicycle and stop, we fall forward. If we go at a low speed, we fall closer than if we go at a higher speed»; b) «To fill a bucket with some water and rotate it»; c) «When riding a carousel, we feel the wind pushing us backwards». The experiments a) and c) have been fully discussed; and the experiment b) was made by students. It is beyond the scope of this report to describe these activities. Nevertheless, we stress that they promoted dialogues about various areas of knowledge, making relationships between theory and practice, including daily life events. In particular, the experiment b) was very useful to understand the effects of rotation.

All this has been shared in MSc class. All the MSc students considered the grass growing device as very useful for modeling multidisciplinary phenomena and for triggering other experimental activities and conceptual debates.

The synergy of the three models in the MSc class

The tides software model developed in a spreadsheet is robust and revealed to be scientifically insightful. It has been useful for computer simulations by especially skilled students. Even for some of these, the model was too mathematical and abstract, and not very appealing to make simulations. Nevertheless, even in these cases, observing the model object (Figure 1 b)) and the results of simulations (illustrated in Figures 3 and 4) showed to be insightful. For all the students, physical models and experiments were needed.

The tidal model used in the classroom helped comprehend some key aspects such as the formation of the two bulges and why there was a bulge away from the centre although all the forces are directed into it. These results were then compared with the spreadsheet simulation.

The grass growing model helped to comprehend some key aspects such as: rotation and centripetal force. The results were also compared with the spreadsheet simulation. It helped to elucidate that there was an exterior bulge even though there were only attraction forces.

In summary: the virtual model was developed by the teacher of the class, and worked always as a reference, because it was mathematically well grounded and represented the physics involved with a greater precision and rigor; and the two physical models were developed by student teachers as project works and were extensively used in experiments. The success of these models and experiments reinforced the students' interest and confidence in the software model. Thus, the set of three models revealed a synergy that promoted in students important additional scientific and pedagogical.

Conclusion

The tides software model developed in a spreadsheet is robust and revealed to be scientifically insightful.

Nevertheless, simpler physical models / experiments were needed as a complement or as a substitute. For stronger reasons, such models / experiments were needed to work with young students of elementary education.

The physical tides model shown on Figures 5 and 6 was used as a complement to the computer model, being more suitable for introductory approaches with young students. It may be improved, particularly using multiple wires with appropriate elastic constants , to model the differential of external forces (exerted by the wires, but modeling the gravitational forces in a very simplified way) in each area of the ring.

The experimental devices and activities shown on Figures 7, 8 and 9 only required accessible equipment and materials and they allowed: to experiment on the influence of gravitational force and of rotation on plant growth, to approach fundamental scientific cross-related concepts, and promoting student skills in research, as well as in experimentation and exploration of knowledge.

The physical modeling and practical physical experiments related to tides and artificial gravity proved to be feasible and useful in developing knowledge and competences by students of 10 to 15 years of age. The two physical models / devices showed to cooperate in young students and MSc teacher students learning about the conceptual field involved in both.

In the MSc class, the set of three proposals presented here – one of software type and two of material type – revealed to be a successful case of the synergy of using virtual and physical resources in Natural Sciences Education processes.

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