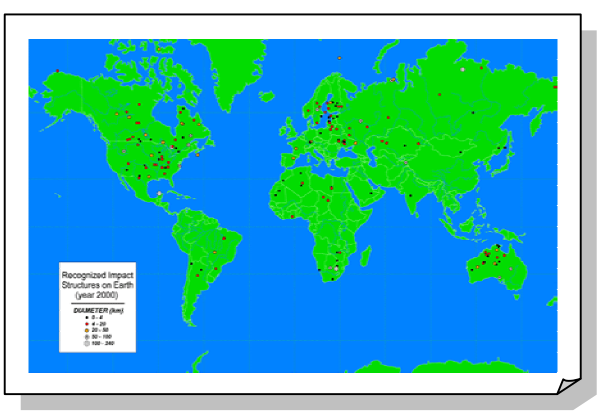
TERRESTRIAL IMPACT CRATERS: WHAT CAN WE LEARN ABOUT THE EARTH AND OTHER BODIES OF OUR SOLAR SYSTEM? DIDACTIC ACTIVITIES. Esther R. Uceda[1], Miguel A. De Pablo[1,2], Gabriel Castilla[1]. [1]Seminar on Planetary Sciences, Universidad Complutense de Madrid, 28040 Madrid. Spain. [2]Área de Geología. Escuela Superior de Ciencias Experimentales y Tecnología. Universidad Rey Juan Carlos. 28933 Mostoles, Madrid. Spain. (depablo@geo.ucm.es).

Introduction. A wide variety of scientific branches attempting to better know other bodies of the Solar System, including our planet Earth, are unified in the Planetary Sciences. This multidisciplinary character is what makes it so attractive to the Secondary Education students, allowing them to reach from the geology or the biology to the physics, the mathematics or the engineering. In the last years, numerous manuals with activities related with the Planetary Sciences for different-aged students [1,2] have been published, and even they have been developed complete didactic units to apply within official curriculum of the Spanish Secundary Education [3,4,5]. In this work we show that, using this multidisciplinarity, students can extract information of the terrestrial impact craters with the aid of some mathematic equations and some simple physical concepts.

Didactic activities. In this work we perform two didactic activities developed with pupils from 9 to 14 years, but it can be accomplished with older-aged students (even universitaries) or with any interested audience. These activities are proposed to serve as a complement to other activities related with impact craters [1], Planetary Geology [2] or Planetary Sciences [4,6]. The first activity is directed to obtain information from the Earth through the study of terrestrial impact craters distribution, and other data as its age. The second activity is focused towards getting informatioaboutof other bodies of the Solar System through an physical and mathematical simplified analysis.

Activity 1: What can we learn about the Earth?. For the development of the first activity, only two things are needed: a coordinated map of the world, and a table with the coordinates of all the terrestrial impact craters accepted by the scientific community [7]. Students may start representing on the map all the craters contained in the table, or any selection of them. The teacher could provide this map, and its complexity will be related with the age of the students. The second phase of this activity consists in the analysis of the elaborated impact craters location map. To help in the analysis, a series of questions as those which we have employed:



- What is the geographical distribution of the craters?
- How many impacts are in the oceans? Why?
- Is there a relationship between distribution and economy?
- Is there a relationship between distribution and geology?
- Is there any relationship between crustal age and craters distribution?
- What was the impact that could trigger the extinction of dinosaurs?

Activity 2: What can we learn about other planetary bodies of our Solar Sistem?. This activity is more complex, since it requires calculations and mathematical demonstrations, but it can be adapted and simplified by the teacher depending on the age on their pupils. The different steps to develop in this activity are:

<u>*Step 1: Impact velocity.*</u> It is not easy to know the impact velocity, but it is possible to make an approximation supposing the collision produced at the velocity of the planet (of the Earth around Sun, for the terrestrial impacts). Supposing a circular orbit, its velocity (v) is expressed by: $v = \Delta S / \Delta t$, where ΔS is the distance traveled in a time Δ*t*. That distance is easily calculated supposing that the body receiving the impact describes a complete circular orbit, therefore is expressed as: $\Delta S = 2 \cdot \pi \cdot r$, where *r* is the radio of the described orbit. Thus, to calculate the impact velocity, the following expression will be applied: $v = 2 \cdot \pi \cdot r / \Delta t$

> *<u>Step 1:</u> Calculate the velocity (in cm/s) of the Earth knowing the distance to the Sun (1 U.A. =150 million of kilometers), and the duration of its year (365 days).*

<u>*Step 2: Impact energy.*</u> The energy detached in an impact, in the form of heat and deformation of the surface, comes from the velocity of the impacting body (Kinetic Energy), that is expressed as: $E_c = (1/2) \cdot m \cdot v^2$, where v is the speed of the impact, and *m* the mass of the impactor. To aproximate this mass, it can be applied a simplification supposing the body is a sphere, whose mass is: $m = \rho \cdot V = \rho \cdot (4/3) \cdot \pi \cdot r^3$, where ρ is the density of the body and *r* is the radio of the impactor. With all this, if we want to know the radio of any body impacting with a planetary surface, we could join the previous equations: $E_c = (1/2) \cdot \rho \cdot (4/3) \cdot \pi \cdot r^3$. Thus, the formula to apply is: $r(cm) = \sqrt[3]{3 \cdot E_c / 2 \cdot \pi \cdot \rho \cdot v^2}$, where the velocity and the density are known values and the energy is a extrapolated value for the equation: $E_c = e^{[(3.33 \cdot LnD) + 54.6]}$ (obtained from a exponential regression of some published data [8]), where *D* is the diameter of the crater.

Step 2: Calculate the radio of the meteorites forming the following terrestrial impact craters, knowing the speed of the Earth (calculated in step 1) and supposing the density of the meteorites as 3 g/cm³.

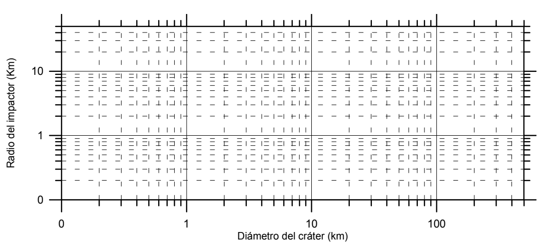
Cráter	Latitud	Longitud	Diámetro (km)	Energy (erg)	Edad (M.a.)	Tamaño impactor (km)
Chicxulub	21º20' N	89º30' W	300.0	10^{32}	65	
Sudbury	46º36' N	81º11' W	200.0	10^{31}	1850	
Popigai	71º30' N	111º00' E	100.0	10^{30}	35	
Kara-Kul	39º01' N	73º27' E	052.0	10^{29}	25	
Boltysh	48º45' N	32º10' E	025.0	10^{28}	88	
Kelly West	19º56' S	133º57' E	010.0	10^{27}	550	
Upheaval Dome	38º26' N	109º54' E	005.0	10^{26}	65	
Zeleny Gai	48º42' N	32º54' E	002.5	10^{25}	120	
Pretoria Salt Pan	25º24' S	28º05' E	001.1	10^{23}	200	

Step 4: Deduce what type of asteroids were those which provoked the different craters of analyzed terrestrial impacts, and where are found, using the next data list of some of the different types of asteroids (and employing the results obtained in the previous steps).

Kind	Ref.	Name	Distance (U.A.)	Diameter (km)	Periodo de rotación (h)	Composition
Internos	2100	Ra-Shalom	0.83	3.4	19.8	Carbonátic
	2062	Aten	0.97	1.0	-	Silicic
	2340	Hathor	0.84	0.2	-	-
	1866	Sisyphus	1.89	10	-	-
	1685	Toro	1.37	4.8	10.2	Condrítico
	1139	Atami	1.95	7	-	Silicatos
Cinturón de asteroides	19	Fortuna	2.44	190	7.4	Carbonático
	21	Lutetia	2.43	115	6.1	Metálico
	2	Pallas	2.77	522	7.9	Carbonático
	1	Ceres	2.77	914	9.1	Carbonático
	704	Interamnia	3.06	334	8.7	Carbonático
	31	Euphrosyne	3.15	248	5.5	Carbonático
Ex	944	Hidalgo	5.82	39	10.1	Carbonático
	2060	Chiron	13.7	200	5.9	Carbonático

Step 3: Crater and impacting body. The size of the bodies that have generated the different impact craters depends on the characteristics of the planetary body (atmosphere, surface type, translation velocity) and on the age of the crater (in principle, at ancient ages, the impacts were more numerous). In spite of this variability, it is possible to observe relationships between the diameter of the impacting bodies and the craters that they produce.

Step 3: Represent in the next graph the diameter values of the impact crater, and the radio (calculated in the step 2) of the meteorites that provoked them. Try to determine if exists some relationship between them.



Step 4: Conclusions. The study of the radio of the bodies that provoke the impact craters allows to better know the dynamics of our Solar System, since it gives an approximation to the type of bodies which generate the impacts and to the region they come from. This information helps to analyze the causes of its displacement, and this allows the planetary scientists to know a little better the Solar System.

Step 5: Other planets and other possibilities. Its possible to repeat the first four steps for the martian (or others planets and satellites) impact craters, to compare the martian and terrestrial impacting bodies. Other possiblility is to repeat the last three steps (step 2 to step 4) with different data about meteorites density and/or kinetic energy for comparisions with the previous results.

Conclusions. The study of the terrestrial impact craters is not only interesting for those studing Planetary Sciences, but it could also be a didactic method for teaching exact sciences (mathematics and physic), experimental sciences (geology and biology), and social sciences (geography).

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