Development of Scientific Analysis Skill by Teaching the Moon Crater Phenomenon

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Abstract

Encouraging the development of scientific analysis skills, critical thinking and logical reasoning skills in the first years of education offers the long-term possibility of fostering scientific, technological, economic and social advancement in the country. This makes it necessary to propose teaching strategies that promote these competences in the classroom. Astronomy is a science that has been linked to the human being since ancient times, so it becomes an ideal tool to achieve this objective, given the high interest it generates in people regardless of age or educational level. A methodology that allows promoting the scientific analysis skills, critical thinking and logical reasoning in high school students, through the implementation of a teaching strategy on the lunar crater phenomenon, is presented in this article. The intervention made it possible to enhance the scientific analysis skills, transforming the cultural terms initially used by the students to refer to astronomical concepts into scientific terms.

Keywords: Space science teaching; fundamental science teaching; physics teaching; astronomy outreach; teaching strategies.

1. Introduction

Astronomy and space sciences are some of the areas of human knowledge that contribute the most to the development of countries in scientific, technological, social and cultural contexts, among others. For example, in the scientific context, space exploration has made possible the development of modern computer systems that have facilitated the analysis of large volumes
of data in other fields (Rosenberg et al., 2014). In the area of technology, the Laser Interferometer Gravitational-Wave Observatory (LIGO), designed to detect gravitational waves in deep space, is also used to analyze the gravitational stability of oil wells (Cardenas et al., 2003). Finally, in the economic and cultural field, The Southern African Large Telescope (SALT) has generated new dynamics in the surrounding areas where it has been built, promoting the development of sectors such as tourism, which benefits the local population (Fernandez et al., 2014).

The above are just a few successful examples of the contribution of astronomy and space sciences to the development of countries. Hence the need to encourage interest in astronomy in society which is achieved, in the first instance through the education of children and young people. Despite the above, these sciences are not present in the curriculum of the Colombian Ministry of National Education for elementary and secondary school, with the aggravating circumstance that new science-related subjects have no place in the short term in Colombia. At the international level, a proposal was submitted in Spain for the inclusion of the subject Astronomy, which did not find a place in the educational system (Salvador et al., 2017).

Faced with this problem, the possibility of promoting critical and scientific thinking through daily activities in the classroom arises as an alternative (Polanco et al., 2022), involving astronomy in this context. For example, Universidad Nacional, in Medellín, Universidad Francisco José de Caldas and Universidad de Antioquia, (Sosa, 2016) carried out research that aimed at evaluating student practice that is, what students do to promote the construction of scientific knowledge taking astronomy as a fundamental element. On the other hand, Ibañez et al., (2017) developed a strategy to teach daytime astronomy using virtual simulation tools. In the meantime, Tarquino et al., (2017), proposed a didactic sequence developing topics of astronomy related with the Earth-Moon dimensions. Now, Universidad Pedagógica Nacional (Méndez & Monroy, 2016) presents a Python design for teaching the Hohmann transfer orbit. In other words, they developed a simulation tool for teaching celestial mechanics.

These research projects show initiatives that have been developed to teach a specific subject related to astronomy. However, these studies do not show whether the teaching of astronomy is a means of enhancing scientific thinking skills in children and adolescents. Consequently, the objective of this study was to enhance the scientific analysis skills achieved by a group of 21 high school students between 12 and 14 years old, through a didactic strategy on the astronomical phenomenon of lunar craters. This article presents the authors’ methodological design, followed by the results obtained and their relationship with both the theoretical and the emerging categories.
2. Methodology

Three moments were created for the development of the methodology: Zone of Actual Development, Zone of Potential Development, and Zone of Proximal Development. A didactic strategy based on the pedagogical theory of social constructivism (Derry, 1999; McMahon, 1997) was designed for the intervention. The methodology is proposed so that other researchers and teachers find in astronomy a way to dynamize the teaching-learning processes in the areas of science, within the framework of the activities that are carried out daily in the classroom.

2.1. Information gathering techniques

The data collection techniques used were participant observation (Bogdewic, 1992; Kawulich, 2005; Spradley, 2016) and group discussion (Flynn & Klein, 2001; Krueger, 1991). The first data collection instrument designed, the participant observation, was used throughout the process, keeping records of what happened through field diaries. On the other hand, the second instrument was built under the guidelines of the discussion group (Figure 1) and applied in two moments during the research process.

Figure 1. Information gathering instrument (discussion group).

Source: Authors.
The first moment in order to describe the Zone of Actual Development, and the second through field diaries. On the other hand, the second instrument was built under the guidelines of the discussion group (Figure 1) and applied in two moments during the research process. The first moment in order to describe the Zone of Actual Development, and the second moment after the teaching strategy was implemented.

Audio recordings were used for the recording of the information, and later they were transcribed and finally discourse analysis was applied.

2.2. Pedagogical proposal

The pedagogical proposal is the pedagogical theory based on social constructivism, considering that "the teaching-learning process is fundamentally a social construction" (Carrera & Mazzarella, 2001, p. 43). According to this model, "learning occurs first at the social level based on interactions, and then on an inter-psychological level" (Hernández, 2017, pág. 24), that is, in a higher-level intellectual process. The theoretical categories of social constructivism are (Figure 2): Zone of Actual Development (ZAD), Zone of Potential Development (ZPtD) and the Zone of Proximal Development (ZPD).

Zone of Actual Development (ZAD): The Zone of Actual Development is based on the premise: "Every kind of learning that the child encounters in school always have a previous history" (Vigotsky, 1979, p. 130). This zone has to do with the level of development of mental functions, as well as with the consequences of the evolutionary cycles (Vigotsky, 1979). It should be added that this zone includes those activities that children can carry out on their own, which is indicative of mental capacity.

Within the framework of the proposed methodology, objective was to identify the elements of scientific foundation present in the Zone of Actual Development of the students. This identification was carried out by applying the discussion group. The questions were designed in an open format (see Figure 1), which allowed understanding, in a transparent way, what the students conceived as astronomy, both from a scientific and from a cultural perspective. About the dark green blocks in the diagram in Figure 2, the sample of students was divided into small groups chosen at random trying to make each group as equal as possible as far as the number of men and women. The intervention started by explaining the methodology. Then, each student had to contribute to the answers to the questions posed, which were presented in a non-directed way, thus allowing any of the participants begin to answer taking into consideration the fact that the objective was related to generating debate between the various points of view.

At this point, the students in each discussion group focused on answering to the questions and, on the other hand, defended or rejected the answers of their peers. After applying the
discussion group, a previous analysis of the information was carried out with views to the concepts related to astronomy present in the ZAD, and once the partial results were known, the design of the astronomy teaching strategy related to the lunar craters was carried out. Figure 3 presents a photograph of the students interacting within the Zone of Actual Development.

Figure 2. Phases of the application of the strategy, from the theoretical categories of social constructivism.

Source: Authors.
Figure 3. Interaction of the participants in the ZAD.

Source: Authors.

Zone of Potential Development (ZPtD): The second moment of the methodology proposed refers to the theoretical category called Zone of Potential Development (ZPtD, Brown & French, 1979). "The ZPtD covers those aspects that are most modifiable and allow for growth with the help of mediators" (Ledesma, 2014, p. 43). Therefore, the ZPtD is understood as the future Zone of Actual Development. In this way, the interaction of students (Figure 4), the work with manipulative objects, and teaching in a non-traditional way enhance the Zone of Proximal Development (Ledesma 2014), and consequently promote the development of the ZPtD.

In this second phase of the research, participant observation was used as an instrument for collecting information (blocks in purple in the diagram in Figure 2). This instrument was designed in order to describe the Zone of Potential Development of the students. This design offered the possibility to develop a broad relationship between peers, which made it possible to analyze how the interaction processes developed. In addition, participant observation allowed understanding in context the comments that arose, the perspectives that each of the groups had on the proposal, the way in which they arrived at the construction of hypotheses, and the way in which these hypotheses were corroborated.
For the implementation of the Zone of Potential Development, the students were divided into small groups. Each subgroup had as materials a container, flour and different objects from the environment that could impact against the container with flour. In this exercise, the objects represented asteroids and the container with flour represented the lunar surface, so the experiment consisted of generating impact craters with different characteristics. Each team had to shape the impact surface in three different ways. For the first type of surface they only had to deposit the flour in the container. For the second type of surface, the members of the groups had to ensure that the impact base was as compact as possible and finally, for the third type of surface, they had to build a series of mountains and valleys, thus simulating the topography of the lunar surface where asteroid impacts had been generated. For each of the previously mentioned surfaces, the students had to drop and then launch with some initial speed each of the objects they took from the environment. These objects were very diverse: rocks, pieces of wood, pencils, and screws, among others. Each of the throws had to be
videotaped in order to proceed with the analysis of the observed phenomenon, its discussion and the construction of conclusions.

After the practical interaction, the students were able to reflect and analyze, individually, what happened in each of the types of tests carried out. Then, the students were asked to form small groups and share among them the perceptions and possible hypotheses that had demonstrated or contradicted the development of the activity. In these small groups, students were asked to reach group conclusions, that is, to reach points of convergence and finally, as a result, to produce an explanatory video where they would show the launches made and define the conclusions they had reached. Finally, in a large group, with all the student sample, all the videos and the conclusions that each group had constructed were viewed and analyzed. This made it possible to continue with the third and last phase of the research, which will be explained next.

Zone of proximal Development (ZPD): The last step in the proposed methodology, and in turn the third theoretical category of social constructivism, is the Zone of Proximal development (ZPD, Fani & Ghaemi, 2011). Gozáñez et al., (2011) defines the ZPD as follows: "It is the distance between the actual level of development, determined by the capacity to solve a problem independently, and the level of potential development, determined through the resolution of a problem under the guidance of an adult or in collaboration with another more capable partner". To infer the Zone of Proximal Development of a student, the discussion group technique was applied again after the implementation of the didactic activity associated with the lunar crater phenomenon. The dynamics was carried out as follows (blocks in orange in the diagram in Figure 2). Again, the sample was divided into subgroups, not necessarily identical to those in the first discussion group, nor to the same groups that worked in the second phase of the methodology. The intervention time was approximately one hour. The questions that energized the discussion are listed in Figure 1. The students debated and defended their answers based on the observations made in practice (Figure 5). In addition, the participants used foundations previously addressed in the working groups created in the second phase of the research. After applying the data collection instrument, data analysis was carried out, in order to describe the qualitative distance between the ZPtD and the ZPD.

For the analysis of the information corpus, a series of techniques guided by discourse analysis were used. Figure 4 presents the flow chart of the instrument developed. In general, the start was the transcription of the information that was stored in audio format. The data processing, after the initial transcription and analysis carried out through discourse analysis, is followed by the triangulation between the theoretical categories of social constructivism, the methodological proposal and the corpus of information. Based on the theoretical categories, the construction of emerging categories, which as their name indicates, are a direct consequence of the analysis of the information provided by the instruments were carried out.
Then, the analysis made it possible to build emerging sub-categories and sub-sub-categories, which will be presented below in the results.

Figure 3. Empowerment of a ZPD member of one of the subgroups graphically representing their perspective of the lunar craters as an answer to one of the questions of the discussion group.

Source: Authors.

3. Results and discussion

Table 1 shows the qualitative differences between ZAD and ZPtD. These percentages are the result of the application of the qualitative speech analysis technique. Thus, each percentage is associated with the frequency with which the respective term was used in the answers. Next, the results obtained in each category of questions with respect to each of the subcategories of answers obtained are discussed.

3.1. Astronomy

The 81.08% of the answers in the ZAD were related to objects in the universe such as planets and asteroids, among others. In another sense, this category was related to the sky in 10.81% of the cases, thus evidencing the cultural conception of scientific aspects, as well as the role played by the family in the construction of knowledge, as evidenced in one of the answers: "...in these days I was trembling, and my mom told me, that it was because of the action of the moon". Finally, in 8.11% of the interventions, astronomy appears in relation to research.
As for the ZPtD, the terms tied to cultural conceptions disappeared, leaving in their place those related only to astronomy. The 61.90% of the answers were related to astronomical objects, while research went on to register 38.10%. In this item, institutions in charge of moving the line of knowledge in astronomy and developing space exploration appeared in the answers.

Figure 4. Validation flowchart of the information corpus analyzed tools.

Source: Authors.
Table 1. Differences between the Zone of Actual Development and the Zone of Potential Development for each category and sub-category of question.

<table>
<thead>
<tr>
<th>Category of Question</th>
<th>ZAD</th>
<th>ZPtD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Astronomy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Universe</td>
<td>81.08 %</td>
<td>Universe</td>
</tr>
<tr>
<td>Sky</td>
<td>10.81 %</td>
<td>Research</td>
</tr>
<tr>
<td>Research Institutes</td>
<td>8.11 %</td>
<td></td>
</tr>
<tr>
<td><strong>Astronomical Objects</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Astronomical Elements</td>
<td>81.63 %</td>
<td>Astronomical Elements</td>
</tr>
<tr>
<td>Astronomical Instruments</td>
<td>16.33 %</td>
<td>Instruments</td>
</tr>
<tr>
<td>Research Institutes</td>
<td>2.04 %</td>
<td>Life On Other Planets</td>
</tr>
<tr>
<td><strong>Crater</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Features</td>
<td>64.71 %</td>
<td>Features</td>
</tr>
<tr>
<td>Generated By</td>
<td>35.29 %</td>
<td>Causes</td>
</tr>
<tr>
<td>Impact Site</td>
<td></td>
<td>Impact Site</td>
</tr>
<tr>
<td>Generated Form</td>
<td></td>
<td>Generated Form</td>
</tr>
<tr>
<td>Impact Surface</td>
<td></td>
<td>Impact Surface</td>
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<tr>
<td>Impact Site</td>
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<td>Generates</td>
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<td>Expel</td>
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<td></td>
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</tr>
<tr>
<td>Features</td>
<td>8.82 %</td>
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<td>Affects Other Places</td>
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<td>Natural Factors</td>
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<td>Human Factors</td>
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<td>Human Factors</td>
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<td>Surface Characteristics</td>
<td></td>
<td>Surface Characteristics</td>
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<tr>
<td><strong>Lunar Crater</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caused By (Generated By)</td>
<td>38.89 %</td>
<td></td>
</tr>
<tr>
<td>Physical</td>
<td>45.16 %</td>
<td></td>
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<tr>
<td><strong>Lunar Crater Features</strong></td>
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<tr>
<td>Optical</td>
<td>38.71 %</td>
<td>Optical</td>
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<tr>
<td>Sensation</td>
<td>16.13 %</td>
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<tr>
<td>Optical</td>
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<td>Generate</td>
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<td></td>
<td>Asteroids</td>
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</tr>
<tr>
<td>Crater Shape</td>
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<td>Crater Shape</td>
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<tr>
<td><strong>Illustrations</strong></td>
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</tr>
<tr>
<td>Explain Features</td>
<td>100.00 %</td>
<td></td>
</tr>
</tbody>
</table>
3.2. Astronomical objects

Regarding ZAD, three sub-categories emerged. In the first place, astronomical elements arise, in 81.63% of the cases, mainly associated with elements of the Solar System. In the second place, astronomical instruments rose in 16.33% of the cases, with the telescope as the protagonist. Finally, the word "NASA" emerged in 2.04% of the answers as a research center. In this regard, in one of the subcategories, the students were asked about terrestrial phenomena due to the action of the Moon, but they did not show knowledge of them. With respect to the ZPtD, the same three categories of answers appeared. Astronomical elements increased to 96%, thus evidencing a greater convergence since astronomical objects are related to the elements that make up the universe. The category of instruments decreased to 2% as instruments are the means to study astronomical objects and are not exactly objects.

Finally, with 2%, life emerges on other planets, as an object of the universe, reflecting the importance of continuing research on questions that have always troubled humanity, such as discovering life in other parts of the universe, and regarding terrestrial phenomena that occur because of an action of the Moon, the explanation of tides emerged as an action at a distance.

3.3. Astronomical objects

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3.4. Crater

The category of the question related to craters yielded two sub-categories in the ZAD, which were related to terrestrial craters and volcanic activity. For the ZPtD, 64.71% of the answers were related to terrestrial volcanoes. Regarding the causes that generate a crater, 35.92% of the answers suggested that these causes are related not only to volcanic activity, but also...
because of an impact. Finally, 31.82% of the answers expressed the importance of the impact site in the formation of a crater.

3.5. Moon crater

In the ZAD, 61.11% of the answers were related to the formation of craters due to volcanic activity, as was the case in the previous question category. As an example, one of the students expressed that a crater is: "What remains after the eruption". In the ZPtD, a significant number of sub-categories are showed, as ten were recorded. This significant number of elements allowed reading what the students understood about what a lunar crater is. In particular, the results were as follows: shape of the craters and their relationship with the object that generates them: 21.30%; impact sites and their relationship to flat or mountainous surfaces: 10%; changes in the surface near the crater site: 8.75%; material detached after impact: 6.25%; possible objects causing craters: 8.82%; characteristics of craters according to the type of surface (sand, rocky, etc.): 8.82%; affectation of other places due to the material expelled by the impact: 7.35%; natural factor in conservation in Moon craters: 20.83%; human factor in conservation in Moon craters: 4.16%.

3.6. Characteristics of the Lunar crater

Regarding the ZAD, the first sub-category that emerged in 45.16% of the answers was the morphology, that is, the shape that the craters took. The subcategory of optical characteristics, associated with the visualization of craters, also emerged in 38.71% of the answers. Finally, the subcategory of sensation emerged in 16.31% which in all answers was classified as rocky surface. As for the ZPtD, 55.32% of the answers were related to the shape of the craters, the depth and the different processes that could have created them. A 40.43% of the answers referred to the fact that, depending on the impact, the crater would take a certain shape, which showed a certain relationship of proportionality in the students. With regard to the formation of the craters due to an external agent, 4.26% of the answers were recorded with analogies such as the following: "...it is like when two cars collide that leaves a dent, in the same way it happens in the Moon, but the crater mark remains there".

3.7. Characteristics of the observation of the Moon

The category of question related to the observation of the Moon yielded two sub-categories in the ZAD. The first, with 51.02% of the answers, was the surface. There the description made by the students about the shape of the Moon was found, explaining that the shadow observed is a human figure. This allowed concluding that there is a strong cultural component in the way students explain scientific phenomena. For example, they re-recorded expressions such as: "...the Moon is chasing us...", or "...if there is no Moon there is no night". In the optical characteristic subcategory (48.98%) the answers given by students to the question of
why the Moon is illuminated are found. With respect to the ZPtD, three subcategories were obtained: surface characteristics 71.05% of the answers, optical characteristics 15.79% of the answers and asteroids as the cause of the craters: 13.16% of the answers. It was demonstrated that the cultural aspects that had been identified in the ZAD disappeared from the answers, to give rise to answers with a purely scientific nuance.

3.8. Images of the Moon

Finally, the students were asked to model the moon. In the ZAD the students made a grey circle and explained the characteristics that are observed on the Moon. In some cases, the drawings showed shadows, which were explained by the students as "holes". On the other hand, in the ZPtD, in 58% of the cases, the students involved the different phenomena that give rise to lunar craters in their explanatory texts. Meanwhile, 42% of the students described the different morphological characteristics of the craters and their relationship to the way they are observed from Earth. For example, the students differentiated the shapes generated by impacts in valleys or mountainous areas, or in sandy or rocky soils. In addition, the term "hole" disappeared from the context.

4. Conclusions

The results of this research show that the teaching of astronomy has enormous potential to develop the scientific ability of analysis in students. This evolution is represented in the change of language, analysis and hypothesis building. In this case, it was observed that after the application of the strategy, students showed clarity about astronomical objects, particularly about the origin and morphology of lunar craters. For example, the students recognized tides as terrestrial phenomena caused by the distant action of the Moon. They also analyzed the effects generated by the collision of asteroids with the lunar surface when craters are created. The development of scientific ability in the students was evidenced in the evolution from a language based on social and cultural context to a scientific language.

The strategy used based on 3 moments of interaction (ZAD, ZPtD and ZPD) awoke some initiative to learn in the students, because in several cases they wanted to delve into certain topics. This shows that it is possible to generate autonomy in the students to learn if appropriate motivation is present. This becomes a challenge for teachers, since it is necessary to go beyond the training process, particularly in basic science education. Good instructional design will lead to a learning activity that will result in the development of scientific thinking skills in students.
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