Impact of the inquiry based-science methodology on learning physics

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Abstract. The stigmatization of natural sciences and mathematics as difficult, boring and non-practical subjects, starting at the secondary levels, has caused an increased disarticulation between the significant learning of physics and the student, this can be reflected in a less development of basic competences, an almost instinctive revulsion of a large number of students towards these subjects and poor results in the tests that are carried out. Reflecting on this situation, we apply the inquiry-based science education. The intervention was carried out in a private calendar B school in the town of Chía, Colombia; Latitude: 4.85, Longitude: -74.05 4° 51’ 0". The participants were 80 students, the instruments used to collect the information were: class observations, surveys, interviews, an entrance, an exit test and another after the exit test. Two specific inquiry based-science type activities were designed: laboratory practices and the manufacture of a device by the student. These two activities in turn had matrices with defined evaluation criteria to evaluate the impact of the intervention. The students found in the investigation, a much more conducive environment for their learning and in the end the proposal allowed to identify positive impacts of the inquiry based-science as well as not so desired results.

1. Introduction

Reflection on the pedagogical task and the interest in continuously and permanently improving the learning strategies that are developed with the students led to the formalization of this intervention. The elementary physics subject in the school of study has been structured according to requirements, habits and models that perpetuate the overlapping of written tests as instruments designed to measure competences over other types of instruments that can also evaluate competences acquired by the student [1-4].

The reality of the school shows that its need to obtain excellent international results as well as in the national tests [3,5] is a strong premise when designing the eleventh-grade curriculum [6]. Likewise, the frequent demand on the part of the parents, in the use of the textbook, or the persistent dependence of the teachers on it [7] becomes an imperative guideline when designing a study plan at school [8]. The custom in using the classroom [9] or the opposition in the use of spaces different from this, where constructive and meaningful experiences can be carried out, adjusted to experimental processes, was a recurrent principle.

The objective of this intervention was to reposition the student as a fundamental axis in the learning process [10], alternating different strategies that allowed his/her progress to be shown in meaningful learning [11] and his/her autonomy towards the educational process [4,12]. In the same way, it had the
firm intention of eliminating, or at least reducing, the common feeling that students have for the subject of physics or the association that they have made of the learning process, with the words annoyance and tiredness [13].

2. Theoretical framework
Teaching by learning was our personal intention in the intervention [14], in such a way that in order to have this proposal as the banner of the innovative project, it was necessary in the first instance try to better understand what science is, how it is produced and what characteristics or patterns it presents. “All my life I have been doing science and I know what it is, but I feel unable to say it; I do not know which foot I put first and which later” [15].

We have all gone to school and somehow, we have had some interaction with science, but when we try to identify its characteristics or try to explain its nature, it is quite a difficult task. If we additionally add factors such as the type of school, the curriculum, the type of teachers it had, the type of student, the particular relationship that they are going to have with science, (specifically in this case with physics) is going to be vastly different [16].

For this reason, in the pedagogical intervention, introductory discussions were held in which the aim was to understand better the nature of science, identify its objectives and common characteristics with other areas of knowledge, and explain its importance in our lives [17]. Specifically, students had to understand why scientific knowledge has merits [18] and likewise promote skepticism as a fundamental aspect for the scientific education of citizens [19].

The Inquiry—based science education (IBSE) brings together aspects previously mentioned such as: student’s shared interest in solving a question [20], knowing how to observe in detail and knowing what is important to observe, arguing and learning within a sequential and organized system that aims to improve written skills, oral skills, citizenship skills and the autonomy of the student in his/her learning process [17]. The IBSE program “La main à la pâte” makes an important contribution by summarizing in ten principles the characteristics of a program of this nature.

The skills that the student can develop through the IBSE situate him/her as a person who is interested in wondering about his/her environment and assuming a reflective and critical position about him/her [21,22], that is why through the empowerment of scientific competences, construction of scientific concepts and acquisition of scientific codes, citizens educated in science will be able to influence the rhythm and essential destinations of their social environment.

3. Methodology
The students who took part in this intervention were eleventh grade students of the physics subject, the total number of participants was 80 for the entrance, exit and time tests. It is worth mentioning that the students were asked to approve the use of the results of the tests, interviews, surveys and class observations, which is why the number of the sample varies in each activity. Table 1 is shown below, which summarizes the information obtained from the instruments used.

The qualitative data consisted of 68 surveys and 20 interviews conducted randomly. The 80 students were divided into four groups; therefore, they were chosen from each of the groups so that the sample of the interviews and surveys was more representative. The quantitative data consisted of the criteria of the evaluation matrices for the laboratories and for the experimental device, with these data it was intended to evaluate how significant the learning was by the students, which were the skills that were most potentiated and which least of all, both with the laboratories and with the design of the device.

This intervention was designed with the objective of simultaneously changing, a learning model in the students and a teaching model in the teacher. For this reason, it started with the introduction of classes that aimed to analyze the nature of science [23]. After having these classes as a preamble, the students began observation and experimentation classes that demanded a different execution than the conventional classroom. That is, the intervention classes were held in the school science laboratory and even in outdoor spaces, where students could much better carry out an inquiry process [24].
When it was considered that the students had constructed a series of concepts and had a host of research questions, which could be directed towards a laboratory practice in which the use of certain scientific skills could be assessed, they were informed about the rubrics of evaluation. Assessment rubrics were planned so that progress in student skills could be assessed, the student had feedback on their work, and there was more authentic and valuable justification from the teacher [25].

**Table 1. Intervention summary.**

| Activity Developed     | Instrument Used                          | Information Obtained                              | Who collected the information | Quantity of information | Objective                           |
|------------------------|------------------------------------------|--------------------------------------------------|--------------------------------|-------------------------|-------------------------------------|
| Model Explanation      | Rubric with evaluation criteria          | Performance in skills outlined in the evaluation rubric | The author of the intervention | 1 rubric per group. 22 selected groups | Determine improvement in certain learning skills |
| Laboratory             | Rubric with evaluation criteria          | Performance in skills outlined in the evaluation rubric | The author of the intervention | 1 rubric per student. 80 selected students | Determine improvement in certain learning skills |
| Class observation      | Video of the class                      | Concordance of the class protocol regarding the inquiry | Foreign teacher               | 4 classes observed      | To analyze and evaluate the relationship between class protocol and inquiry |
| Initial test           | Initial test                            | Level of knowledge                                | The author of the intervention | 99 tests                | Evaluate the progress of the learning from the beginning of the intervention. |
| Final test             | Final test                              | Level of knowledge                                | The author of the intervention | 50 random tests         | Evaluate the progress of the learning from the beginning of the intervention. |
| Survey                 | Survey                                  | Opinion categories and satisfaction values         | The author of the intervention | 68 surveys carried out  | Measure the degree of satisfaction with the intervention |
| Interview              | Semi-structured interview                | Opinion categories and satisfaction values         | The author of the intervention | 20 interviews carried out | Measure the degree of satisfaction with the intervention |

4. Results

4.1. Student’s performance level
The Figure 1 and Table 2 shows how many students do you have in each criterion in the three performance categories: complete, satisfactory and unsatisfactory. Note that the criterion with the highest number of students is punctuality (criterion 10) and the one with the lowest number of students is conclusion from data collection and bibliographic review (criterion 8).

4.2. General histogram
This shows in a global way, the behavior of the 800 evaluation criteria (80 students, multiplied by 10 criteria) in the laboratory activity. As it can be seen, the highest number of criteria is located in the satisfactory category (332), then the complete category continues with 296 criteria and finally the unsatisfactory category with 172 criteria. In other words, the highest number of criteria evaluated in the
students, were located in the satisfactory category with 41% of the total number of criteria, 37% of the total criteria were located in the complete category, while the unsatisfactory category has the 22% of the total criteria. From these results we can insinuate that the impact of the intervention was positive in the students, regarding the promotion of competences related to the inquiry [24]. Additionally, a possible interpretation of Figure 2. is that its distribution could be Gaussian, since the highest concentration of criteria is found in the intermediate category (satisfactory), while the extreme categories (complete and unsatisfactory) have a lower number of criteria per student.

![Figure 1. Performance level students in the laboratory by criteria. (First column is complete level; second column is satisfactory level and third column is unsatisfactory level).](image1)

**Table 2.** Descriptive statistics for the laboratory evaluation categories.

| Range    | Complete 9-73 | Satisfactory 3-51 | Unsatisfactory 1-46 |
|----------|---------------|-------------------|---------------------|
| Mean     | 29.6          | 36.2              | 17.2                |
| Median   | 26            | 33.5              | 16                  |
| Standard deviation | 19.2          | 14.4              | 13.2                |

![Figure 2. Total evaluated criteria in each category.](image2)

4.3. *Correlations between skills*

Table 3. shows the correlations between skills evaluated for the complete category, showing the notable impact that the intervention has for certain skills, although it also shows the weak correlation among others.
5. Discussion

According to the objectives set in the intervention, the implemented proposal should promote a closer relationship between the students and the physics learning, for the convenience of the intervention the students found in the inquiry, an environment much more conducive to their learning. 70 survey responses are related to the improvement of the educational environment, the inclusion of debates and the attractive structure of each activity [26]. In the same way, the answers in the interview have as a common denominator a high satisfaction index [27], expressed in phrases such as: “it was favorable because it was applicable and there was understanding of concepts”. This "healthy" disposition can explain the behavior of the first evaluation criterion (planning of an experimental activity), both in the laboratory and in the design of the experimental device, because the students responded with great enthusiasm when it was inquired about some phenomenon related to the waves.

The first four criteria of the laboratory matrix (1. Identify research question, 2. Confirmation or invalidation of a prediction, 3. Data collection and instrument calibration and uncertainty, 4. Operational skills) and the first of the experimental device (1. Planning of an experimental activity based on a problem situation) gather more than 70% of students of the intervention, between its complete and satisfactory categories, which proposes that the greatest impact of the intervention could be in these abilities. With this in mind, directing natural science learning toward inquiry may be easier and less traumatic than it may seem. Curiosity is the most precious potential, but also the most abundant in our students, fundamental reasons for a reorganization in the teaching of natural sciences [20].

Now let's take into account the low correlations presented by the intervention, in these it can be seen that the inquiry does not turn out to be the magic formula of teaching, but on the contrary, it needs a didactic scaffolding in terms of teaching strategies, it is say it needs to be complemented with other methodologies according to the planned objectives in the subject. The correlations between variable management, analysis of results, conceptual framework and bibliographic sources were very poor. Two factors that are probably related are striking: a) these criteria require some mathematical work. b) Surveys and interviews highlight that the number of hours per week that the physics class had was insufficient. Two questions then arise around this: Does science inquiry take more time than other teaching strategies? Is there an efficient communication channel between problem solving and inquiry? [28].

As a first measure, this intervention is not intended to answer the two previous questions, it only encourages a debate in which certain characteristics are identified, as a result of their results. When each student in the class is asked about their prior knowledge on a topic, their particular interests in delving into it, and their suggestions for establishing research methods, learning is somewhat individualized [4].

Table 3. Correlations between skills.

|       | C1    | C2    | C3    | C4    | C5    | C6    | C7    | C8    | C9    |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| C1    | N.A   | 0.66  | 0.26  | 0.57  | 0.46  | 0.36  | 0.59  | 0.47  | 0.18  |
| C2    | 0.66  | N.A   | 0.36  | 0.59  | 0.44  | 0.25  | 0.39  | 0.5   | 0.25  |
| C3    | 0.26  | 0.36  | N.A   | 0.22  | 0.16  | 0.08  | 0.15  | 0.02  | 0.35  |
| C4    | 0.57  | 0.59  | 0.22  | N.A   | 0.5  | 0.5   | 0.45  | 0.49  | 0.14  |
| C5    | 0.46  | 0.44  | 0.16  | 0.5  | N.A   | 0.26  | 0.42  | 0.58  | 0.26  |
| C6    | 0.36  | 0.25  | 0.08  | 0.5  | 0.26  | N.A   | 0.33  | 0.5  | 0.14  |
| C7    | 0.59  | 0.39  | 0.15  | 0.45  | 0.42  | 0.33  | N.A   | 0.52  | -0.02 |
| C8    | 0.47  | 0.5   | 0.23  | 0.49  | 0.58  | 0.5  | 0.52  | N.A   | 0.11  |
| C9    | 0.18  | 0.25  | 0.35  | 0.14  | 0.26  | 0.14  | -0.02 | 0.11  | N.A   |

C1 Planning an experimental activity based on a problem-situation
C2 Confirmation or invalidation of a prediction
C3 Data collection, instrument calibration and uncertainty
C4 Operational skills
C5 Variable management
C6 Analysis of results
C7 Conceptual framework and bibliographic sources
C8 Conclusion from data collection and bibliographic review
C9 Auto-evaluation
which can be in which the time of the intervention is personalized and therefore extends more than planned for some cases.

There is a particular case that deserves special analysis: the correlation between criterion 3 (data collection) and criterion 6 (analysis of results) is the lowest of all (0.08). This can show that on several occasions, teachers assume an automatic causal relationship, in several of the competencies that students seek to develop. Being more specific, that a student makes a good record of data, it is not a guarantee that they will carry out a good analysis of them. The concurrence by the teacher must be explicit, both for one competition and for the other, and of course, for each and every one of the competences that are intended to be developed [19,27].

This pedagogical reflection yearns that academic initiatives are installed on it that discover the student as a holistic and at the same time individual being, in their approach to learning [4]. This innovation aspires that future proposals try to cultivate in the students the autonomy and responsibility towards their learning, so that in this way they face the challenges of the present and build a better world with their talent [29,30].

6. Conclusion

Regarding the two objectives set out in the intervention: 1. Establish a more attractive academic strategy for students and 2. evaluate the impact of inquiry-based science education, we can affirm that they were achieved because the students perceived this innovation, much closer to their learning of science, this, taking into account the satisfaction index shown by surveys and interviews. It can be observed that almost 90% of the students who were part of the intervention found this class strategy much better since they see it as a more natural way of learning a natural phenomenon.

In the second instance, the present study shows an interesting element: Inquiry Based-Science Education is not effective for all the skills that teacher wants to strengthen in students. It is useful and pertinent for a specific group of abilities that are related to operational skills and planning of scientific activities, but it requires a pedagogical scaffolding from other methodologies, to be able to potentiate other skills that are more related to mathematical processes of analysis and abstraction.

References

[1] Martínez A, Noguera C, Castro O 1994 *Currículum y Modernización: Cuatro Décadas de Educación en Colombia* (Bogotá: Magisterio)
[2] González J, Dussán L, Taborda J 2015 *Revista Latinoamericana de Estudios Educativos* 11 45
[3] *Organización para la Cooperación y el Desarrollo Económico (OECD) 2014 Results: What Students Know and Can Do – Student Performance in Mathematics, Reading and Science* (Paris: Organización para la Cooperación y el Desarrollo Económico)
[4] Pozo I 2006 *Aprender y Enseñar Ciencia* (Madrid: Ediciones Morata, S.L.)
[5] *Senge P 2002 Escuelas que Aprenden* (Bogotá: Grupo Editorial Norma)
[6] Uribé C 2001 *Pasemos al Tablero: Diez Años de Estudio de Evaluación de la Calidad de la Educación Primaria en Colombia* (Bogotá: Centro Editorial Javeriano)
[7] Angulo J, Barquin J, Perez A 1999 *Contextos Educativos 2* 311
[8] Bonafé M J 2002 *Políticas del Libro de Texto Escolar* (Madrid: Ediciones Morata, S.L.)
[9] Valcarcel M, Hernández E, Blanco G 1990 *Problemática Didáctica del Aprendizaje de las Ciencias Experimentales* (Murcia: Universidad de Murcia)
[10] Gimeno J 1991 *Diseño Desarrollo e Innovación del Curriculum* (Madrid: Ediciones Morata, S.L.)
[11] Ausubel D, Novak J, Hanesian H 1978 *Psicología Educativa. Un Punto De Vista Cognoscitivo* (México: Trillas)
[12] Freire P 1970 *Pedagogia del Oprimido* (Montevideo: Tierra nueva)
[13] Dewey J 2000 *Experiencia y Educación* (Buenos Aires: Losada)
[14] Amat O 2010 *Aprender a Enseñar* (Barcelona: Profit)
[15] Feynman R 1969 *The physics Teacher* 7 313
[16] Córdova J L 1992 *Educación Química* 3 88
[17] Worth K, Duque M, Saltiel E 2009 *Designing and Implementing Inquiry-Based Science Units for Primary Education* (Francia: La main a la pate)
[18] Bell R L, Lederman G 2003 Science Education 87 352
[19] Garritz A 2006 Revista Iberoamericana de Educación 42 127
[20] Splitter L, Sharp A 1999 La Otra Educación: Filosofía Para Niños y la Comunidad de Indagación (Buenos Aires: Ediciones Manantial)
[21] Campos A 2007 Pensamiento Crítico Técnicas Para Su Desarrollo (Bogotá: Aula Abierta)
[22] National Research Council 1996 National Science Education Standards (Washington: The National Academies Press)
[23] Mccomas W 1998 The Nature of Science in Science Education: Rationales and Strategies (Netherlands: Springer)
[24] Mccain G 1982 The Game of Science (Salt Lake City: Brooks/Cole Pub Co)
[25] Cano E 2015 Profesorado 19 265
[26] Duran E, Ballone D 2005 Journal of Elementary Science Education 17(2) 1
[27] Tma J 2014 Science Education International 25(1) 19
[28] Raes A, Schellens T, De Wever B, Vanderhoven E 2012 Computers & Education 59 82
[29] Solbes J, Vilches A 1989 Interacciones Ciencia/Técnica/Sociedad: Un Instrumento de Cambio Actitudinal. Investigación y Experiencias Didácticas (Valencia: Universitat de Valencia)
[30] Aikenhead G 1985 Science Education 3 15