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INVESTIGATING STUDENTS' CONCEPTUAL CHANGE ABOUT COLOUR IN AN INNOVATIVE RESEARCH-BASED TEACHING SEQUENCE

Estudo da mudança conceptual no contexto de uma sequência pedagógica inovadora sobre a cor baseada em investigação em ensino

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Abstract

This paper is the second part of a multiphase study investigating the impact of a mathematical model, the Addition Table of Colours (ATC), in the learning of colour phenomena. The ATC instruction was undertaken in several 8th grade classes in three different Portuguese schools (250 students) and included collaborative activities through Lab stations model. In the control group (204 students), the colour phenomena were taught in the traditional way, with the goals set by the teachers, without any intervention of the project. The two groups of students were compared in terms of content knowledge acquired in the learning of this subject through comparison and analysis of their pre and post-tests. Quantitative analyses of the pre/post-tests revealed five variants of students' representations about this phenomenon. We found that the *ATC* model, inserted in an interactive and carefully designed teaching environment, is more effective in promoting conceptual change and scientific understandings of colour phenomena.

Keywords: Colour; Misconceptions; Conceptual change; Middle school.

Resumo

Este artigo é a segunda parte de um estudo que investiga o impacto de um modelo matemático, a Tabela de Adição de Cores (ATC), no aprendizado do fenômeno de cor. A instrução ATC foi realizada em várias classes do 8.º ano em três diferentes escolas portuguesas (250 alunos) e incluiu atividades colaborativas através do modelo de estações laboratoriais. No grupo de controlo (204 alunos), o fenômeno de cor foi ensinado de forma tradicional, com as metas estabelecidas pelos professores, sem qualquer intervenção do projeto. Os dois grupos de alunos foram comparados em termos de conhecimento de conteúdo adquirido na aprendizagem deste assunto através da comparação e análise de seus pré e pós-testes. Análises quantitativas do pré / pós-teste revelaram cinco variantes das representações dos estudantes sobre esse fenômeno. Verificámos que o modelo ATC, inserido em um ambiente de ensino interativo e cuidadosamente construído, é mais eficaz na promoção de mudança conceitual e compreensão científica do fenômeno de cor.

Palavras-chave: Cor; Concepções alternativas; Mudança conceptual; Ensino fundamental.

INTRODUCTION

Previous research has shown that colour phenomena are among the most delicate subjects in the teaching for young children, mostly because of the students' intuitions and ideas that arise naturally by over generalizing from their personal everyday experiences (e.g. Chauvet, 1996; Feher & Meyer, 1992; Osborne et al., 1993; Viennot, 2002; Woolf, 1999).

Table 1 shows the most frequent ideas students have about colour phenomena (e.g. Chauvet, 1996; Feher & Meyer, 2002; Langley et al., 1997; Viennot, 2002; Woolf, 1999). Almost all studies have indicated the flaws in students' conceptions of light propagation (Saxena, 1991; Selley, 1996; Watts, 1985) and their everyday experiences with painting as the main factors responsible for their own understanding of the colour phenomena after a formal instruction. For the majority of students "adding lights" is the same as painting (Feher & Meyer, 2002; Leite & Sá, 1997; Woolf, 1999) and colour is a property of the object.

Table 1 – Students' conceptions about the colour phenomena

Colour is a property of the object and is independent of light falling on it or the filters placed over it;
When white light passes through a coloured filter, the filter adds colour to the light;
The colour of an object is a property of the object that remains unchanged under white light but could be changed by coloured light;
Dark colours cover light colours;
The mixture of lights follows the same rules as the mixture of the paints;
The colour of an object is a mixture of its own colour and the colour of the incident light;
The light has colour and gives its own colour to the object;
White light is colourless and clear, enabling you to see the real colour of an object;
Black and white are colours;
The colour of the shadow is always the colour of the light source.

These students' pre-instruction conceptions of the colour phenomena, revealed in interviews and questionnaires, indicate that the naive conceptions above mentioned are not randomly organized in the students' mind; instead they appear through coherent internal schemes used consistently in different contexts (Moreira & Lagreca, 1998).

On the other hand, in a recent study, Martinez-Borreguero *et al.* (Martinez-Borreguero et al., 2013) found that students' misconceptions about colour are organised in the form of four mini-theories. Each mini-theory was associated to one specific misconception. However, when faced with more complex settings, like mixtures of lights and paints/filters, student thinking integrates more than one single concept. These findings are in line with the perspective that students have internal insights of the world around them, which are sometimes revised and reconstructed. In the commonly accepted constructivist model of learning, students actively make a cognitive effort of reorganizing their knowledge structure, rather than simply acquire new information.

In the last decades, teachers and researchers worldwide have become particularly sensitive to the students' naive knowledge, often scientifically unsound, because of its importance in the learning process. According to Vosniadou, the students begin their process of knowledge acquisition by organizing their personal everyday experiences in coherent ways of thinking (Vosniadou, 1998; 2002). These experiences lead sometimes to internal representations, supporting understanding, reasoning and prediction, despite being mostly scientifically flawed theoretical frameworks. Chi and Roscoe highlighted two kinds of naive knowledge: misconceptions that can be easily and readily revised through instruction, and misconceptions which are very robust and highly resistant to change (Chi et al., 2002; Chi, 2008).

Even so, according to the researchers, these common-sense beliefs are very stable and conventional physics instruction does little to change them. Pre-instructional understandings are a common and delicate problem in the teaching field because they often remain after formal instruction or, at least, interfere with learning, frustrating the intended learning outcomes.

As such, literature in this field is important not only because it throws light into the students' way of thinking and into the learning processes but also because it gives important clues about what is to be taught and about which strategies and materials will be more appropriate (Chiu & Lin, 2005; Driver, 1989; Eryilmaz, 2002; Grosslight et al., 1991; Treagust et al., 1996; Viennot, 2001).

Constructivism in its many formats has become a dominant view of learning among researchers and science educators. The process by which students accommodate the "new knowledge" with the existing internal ideas was analysed and studied by many theorists and the conceptual change was one of the outcomes of this reflection. The conceptual change model has its roots in Ausubel's Assimilation Theory of meaningful learning (Ausubel, 1963; 1968). Ausubel made the sharp distinction between learning by rote, and the meaningful learning where the student spontaneously seeks to integrate new knowledge (concepts and propositions) into what they already know.

Somehow, conceptual change is a kind of teaching model that takes into account the students' misconceptions in order to reconstruct them in scientific knowledge. The term "conceptual change" varies in meaning among researchers, because it can occur at different levels, so different researchers assess diferently the existence of conceptual change when describing similar learning outcomes (Duit & Treagust, 2003).

Although Posner et al. did not provide a formal definition of conceptual change (Posner, 1982), they listed some terms that promote accommodation in student thinking. For instance, there must be dissatisfaction with existing conceptions and the new approach must be intelligible, fruitful and plausible. Thus, in order to bring about conceptual change, it is crucial to promote students' awareness of the limitations of their own ideas. However, it is not enough to induce cognitive dissonance, the students have to feel the need for a revision and the new "model" to be acquired has to be convincing (Hewson & Hewson, 1983; Hewson & Hewson, 1984; Hewson & Thorley, 1989). Thus, the instructor must design instructional situations that will confront the students with their ideas and bring them in line with standard scientific explanations.

Conceptual change is a powerful framework for improving science teaching and learning. However, researchers around the world look upon the teaching strategies in the conceptual change model (and upon Constructivism) as too empiricist (Osborne, 1993 & Mortimer, 1996). In fact, there are significant limitations if we only take the "classical" conceptual changes approaches (developed in the 1980s and early 1990s), with a single epistemological orientation and discarding ontological and social/affective positions (Duit & Treagust, 2003). Indeed, several authors, including Pintrich et al. (e.g. Pintrich et al., 1993; Sinatra & Pintrich, 2003) have emphasised that social and affective aspects of personal and group learning (self-efficacy, classroom social context, expectations, beliefs…) can limit conceptual change. In a similar vein, in the last years, the research in conceptual change highlighted the metaconceptual awareness of the students and stressed metacognition as the potential mediator for improving learning (Georghiades, 2000).

The present paper is concerned with the teaching of colour to young students, and presents a study carried out with middle school students (12-13 years of age). The study involved curriculum development and a mid-size quasi-experimental study (around 450 students), to assess and compare knowledge gain and conceptual change among experimental and control groups. The curriculum development was built around previously misconceptions of colour phenomena and consisted of the following:

a) a central concept, that unifies the mental operations related to the prediction of perceived colour in a variety of situations, and is offered as a rational and plausible framework, that can replace previously existing representations: the ATC model.

b) a set of materials and experimental investigative activities, fostering a prediction-experimentation/observation-discussion cycle, that offered the opportunity to extend experiences in the perception of colour, in a reflective and critical environment.

The aim of this study is to identify a pattern of students' internal representations about the colour phenomena and analyse how do they change as a result of two different learning environments: Traditional instruction *vs.* ATC instruction. This study was possible thanks to the analysis of the students' results in pre and post- tests. Based on the students' internal representations about the colour phenomena, this study analyzes students' conceptual change, both in the experimental and in the control groups.

ATC (ADDITION TABLE OF COLOURS) MODEL

There is a consensus among experts that the teaching of colour requires a theoretically effective instructional strategy including a detailed comparative analysis and synthesis of the additive and subtractive mixture (Colin et al., 2002; Viennot, 2002). The colour of an object and the resulting colour of the mixture of paints or lights are part of the same phenomena, which should be accounted for by a single theoretical framework. Thus, the development of a theoretical understanding of this subject is essential to an appropriate learning.

Faced with these requirements, we developed a simple mathematical model, the Addition Table of Colours (ATC), to introduce the colour phenomena (Mota & Lopes dos Santos, 2014; Mota, 2017). This conceptual model blends additive and subtractive mixture in a single theoretical framework and accounts for colour perception as the result of the interaction of the physical properties of light with physiological and psychological features of the human visual system (Boynton, 1990). This model was designed based on the concept of colour perception as the outcome of the response of three types of visual cones and the students, developing and solving simple equations, become aware of the composition of the incident light and understand how it interacts with matter, since the composition of the transmitted/reflected light is also given by the equations.

Broadly speaking, the ATC model is based on a single procedure, by which students build equations for colour combinations, by attributing the plus signal when they have body lights and the minus signal in the case of filters or objects, *i.e.,* when light is absorbed. In all the terms of the equation only primary colours (red, blue and green) are used just like in the human optical system.

For instance, what does a magenta object (with visible light) look like when covered with a green filter and illuminated by a natural light? Using the ATC model, we can assume:

Visible light: + RED + GREEN + BLUE
Green filter: - BLUE - RED
Magenta object: - GREEN

$$+\cancel{\text{RED}} + \cancel{\text{GREEN}} + \cancel{\text{BLUE}} - \cancel{\text{RED}} - \cancel{\text{BLUE}} - \cancel{\text{GREEN}} = \text{BLACK}$$

The Addition Table of Colours (ATC) proved simple enough to be grasped by young students, and, at the same time, provided a direct correspondence between the students' mental operations in predicting colour in all type of settings, and the physical processes (spectral composition of illuminating light frequency dependent absorption, by filters or objects), determining the perception of colour (Mota & Lopes dos Santos, 2014).

METHOD

Participants and design of the study

Four hundred fifty-four 8th grade students (aged 12-13) were involved in this study; 204 from a control group and 250 from an experimental group. Only one school had students from both groups, as shown in Table 2. A quasi-experimental design was used; the two groups were not created through random assignment; potential non-equivalence between the two groups was avoided by choosing schools located nearby and drawing the population from socio-economically equivalent regions. A pre-test was used to test the possibility of the two groups be non-equivalent.

The eight teachers recruited for the experimental group had more than ten years of teaching practice and they volunteered to participate in the project.

Table 2 – Distribution of students (by groups and schools)

		Schools						
		IND	JML	S	FV	SCD	AH	TOTAL
Group	Experimental	25	190	35				250
	Control			80	50	54	20	204

Students' internal representations of colour phenomena

Previous research about the colour phenomena already has established that children’s ideas about colour are organized in coherent and systematic ways (Feher & Meyer, 1992). A detailed analysis of the misconceptions allowed us to categorize them into different qualitative levels and formulate five variants of students’ representations of colour phenomena (Table 3).

These representations are very solid and resistant to replacement by new knowledge and new representations, unless these are presented in an intelligible and rational way. The systematic approach summarized in Table 3 was the starting point of the pre/post-tests and all of the pedagogical materials, since these were designed to foster conceptual change in the students’ mind.

Table 3 – Students´ internal representations of colour phenomena.

Categories	Misconceptions - Criteria		Students’ internal representations description	
E	Colour is a property of the object and is independent of light falling on it or the filters placed over it.	Mixing paints and mixing lights have the same result regarding the final colour.	The colour is an intrinsic property of an object, so the colour of an object never changes.	The mixture of lights follows the same rules as the mixture of paints.
D		Mixing paints and mixing lights have different results regarding the final colour.	The colour of an object and the resulting colour of the mixture of paints or lights are different phenomena, so they are explained through different theoretical frameworks.	The mixture of lights does not follow the same rules as the mixture of paints.
C	Dark colours cover light colours; The colour of an object is a mixture of its own colour and the colour of the incident light; The light has colour and gives its own colour to the object; A coloured filter placed in front of a white light modifies the clear beam by adding colour to it.	Mixing paints and mixing lights have the same result regarding the final colour.	The colour is not an intrinsic property of an object, it changes according to the incident light and/or the filter placed over it.	The mixture of lights follows the same rules as the mixture of paints.
B		Mixing paints and mixing lights have different results regarding the final colour.	The colour of an object and the resulting colour of the mixture of paints or lights are different phenomena, so they are explained through different theoretical frameworks.	The mixture of lights does not follow the same rules as the mixture of paints.
A	No misconceptions		The colour perceived is related with the properties of the object, the incident light and the human visual system. The additive and subtractive mixture are understood in a single theoretical physical framework able to explain the colour phenomena. Students correctly identify the conditions for applying the additive and subtractive model, in order to predict the perceived colour.	

Note: Misconceptions related with shadows were not considered because they are a variant of the colour phenomena and are also related with the students' flaws in the conception of light propagation.

Procedure

The colour teaching module was implemented in two interactive lectures and one lab class (a total of 180 min). It was designed to create the conditions to promote conceptual change, because it took into account the students' internal representations of colour phenomena (Table 3) and the scientific knowledge behind it. The teachers involved in the project were given the lesson plans (with well-designed objectives) and pedagogical materials in properly identified kits to facilitate the storage and subsequent use.

The instruction aimed to use well-designed and dramatic experiences, with unfamiliar or unexpected effects involving colour phenomena to facilitate the change in the learner's conception. Classes were carefully thought out and rigorously planned in order to make the students feel the limitations of their own ideas and, naturally, look for new understanding schemes able to provide a reasoned and coherent comprehension of this subject. Students could see, experimentally, that their predictions were wrong and their internal representations failed to account for their observations.

The lab class was developed according to the lab stations model (Mota et al., 2013). The class was divided into four experimental stations (lab stations), each lasting ten minutes. Students were divided in groups of three and went from station to station, performing the planned experiments and answering questions on a worksheet. This allowed a reduction of the material requirements, an increase in the variety of experiments, and a better workflow from students. In the experimental stations, students could carry out everyday observations related to additive and subtractive mixture (handling paints, colour pencils and lights) and explore coloured shadows on a white screen, always in a collaborative environment. All of the materials were designed to promote a gradual process during which initial students' pre-instructional conceptions of everyday experience were continuously enriched and restructured.

Hands-on laboratory activities were an important part of instruction because the students needed to have time to feel that their beliefs were flawed and to practice the new model in many different environments. Changing students' prior ideas and beliefs is a slow and gradual process that could be facilitated by the participation in a variety of activities designed to challenge their alternative conceptions and help them to reinforce the correct scientific view. The experiments used are extremely simple and inexpensive (except for the apparatus *Colour Addition Spotlights* used to demonstrate the additive mixing).

The students were constantly requested to predict, with ATC, and check the result afterwards. All experimental stations were designed to allow a prediction-experimentation-discussion cycle in order to foster reasoned experimentation and to allow early development of scientific abilities.

In Lab Station 1, students were asked to put alternately blue, yellow and green plasticine within a black box (shoebox painted black and properly sealed) and focus on it red and blue lights. After, they had to justify their observations with drawings based on incident and reflected rays with the correct colour pencils. At the end of the station, they were asked to predict colour perception in other situations with different lights focused in different objects (Figure 1).

Figure 1 – Lab Station 1

In Lab Station 2, the students had to predict the colour perceived when different types of cellophane (red, green and blue) are placed on yellow plasticine and then verify the predictions with the ATC model.

After, the students had to make predictions in other contexts (Figure 2).

Figure 2 – Lab Station 2

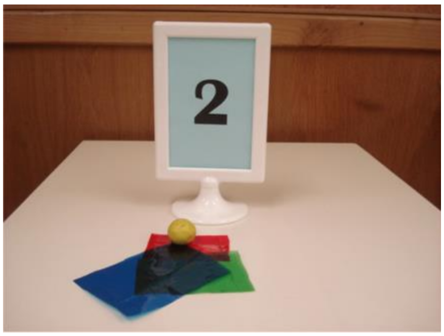
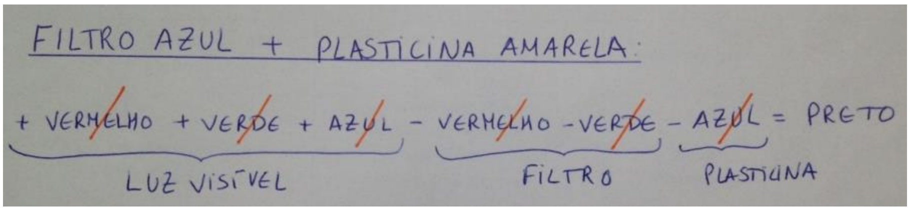


Figure 3 shows an example answer (in Portuguese) of one of these types of questions in Lab Station 2. In this task, students predicted the following situation: What does a yellow plasticine (with visible light) look like when covered with a blue cellophane and illuminated by a yellow incident light?

Figure 3 – ATC model applied in a prediction, in Lab Station 2.



The coloured shadows on a white screen were explored in the Lab Station 3. The apparatus *Colour Addition Spotlights* was used to demonstrate the additive mixture and to discover many kinds of coloured shadows, enabling students to understand the conditions for its formation.

In the Lab Station 4, students were required to mix paints (gouaches) and predict the perceived resulting colour. Also, in this experimental station, the students manipulated magenta, yellow and cyan filters and had to demonstrate the results observed (Figure 4). The lab worksheet and all the material used in the lectures and in the lab are available, in Portuguese[1].

Figure 4 – Lab Station 4

At the end of each lecture, students did a very short test (ten minutes). These mini-tests, just like the lab worksheet, and other similar tasks in the lectures, were used for formative assessment. Studies in this field show the importance of the all-time feedback to the students (and also to the teachers) and the learning

[1] http://faraday.fc.up.pt/Faraday/Members/anarita/8/modulo4.

gains from systematic attention to this kind of assessment (Black & William, 1998).

In the control group, the time spent in the colour teaching was very similar. However, there was no laboratory class (the Portuguese curriculum guidelines advise, but do not require it). The control group teachers were not aware of the main principles and features of this intervention project.

Pre/Post-tests

The knowledge assessment questionnaire, simultaneously pre and post-test, was developed by us and administered individually to the students from both groups before and after the colour instruction. More details about its construction, validity and reliability can be found in the first part of this research (Mota & Lopes dos Santos, 2014). An English translation of the colour test can be found in the supplementary material (Appendix A).

RESULTS AND DISCUSSION

Pre/Post-tests analysis

In the first part of this multiphase study, we presented a global and rough statistical analysis of the pre and post-tests in both groups (Mota & Lopes dos Santos, 2014). The results in the two samples, in pre-tests, were not significantly different. Both groups increased score from pre to post-test, but the mean of the post-test in the experimental group (M = 5.33, SD = 1.554) was significantly higher than in the control group (M = 3.30, SD = 1.766). The normalized gain of the experimental group was 64.8% against 24.2% for the control group.

In the second part of this study, we will analyse, in more detail, the students' answers in each test, in order to have a deeper understanding of their internal representations.

Broadly speaking, the results of the pre-tests corroborate previous studies regarding typical misconceptions (detailed data is in the supplementary material – appendix B). The answer frequencies in each question are very similar for both groups:

- In question 1, in both groups, for the majority of the students, when a green plant (under sunlight) is placed in a dark room with a red light focus on it, the plant changes its colour because the colour of the light blends with its own colour.
- Question 2 is a reference question since the answer was in the pictures at the beginning of the test. The correct option was selected by most of the students in both groups.
- The answers to question 3 showed that students did not know that Black, White or Grey are not considered colours.
- In question 4, students reveal again misconceptions about colour by supporting the statement that a yellow object (in sunlight) cannot appear black when is illuminated under other conditions. This result suggests that for the majority of students in both groups, the colour is an intrinsic property of an object, so it never changes.
- In question 5, there were two favourite answers: b) and e). The choice of answer b) may be due to an interpretation of a shadow in terms of a subtractive mixture. The answer e) may correspond to a correct interpretation or may have been chosen by students who believe that there are no coloured shadows.
- The majority of students answered correctly question 6; they agreed that all cats are grey in the dark because at low intensities, our visual system does not perceive colour. Curiously, approximately one quarter of the students (in both groups) think that the colour is an intrinsic property of the object.
- In question 7, the students showed again confusion between overlapping beams and mixing paints; 53,9% of students in the control group and 52,8% of students in the experimental group think that the colour is always determined as the result of a mixture of paints.

We also analysed the percentage of students that improved their knowledge from pre to post-test in each question. The results are in the Table 4.

Table 4 – Percentage of students that improved their knowledge from pre to post-test in each question

		Questions						
		Q1	Q2	Q3	Q4	Q5	Q6	Q7
Group	Experimental	66.00	25.60	62.80	68.40	52.80	25.20	46.00
	Control	39.71	25.49	17.65	41.18	29.90	13.73	22.55

The experimental group had better results in all questions. It was surprising that in the question *"Are all cats grey in the dark?"* (Q6), the control students had worse results in post-test; they probably "unlearned" after the instruction. In the experimental group the scores in all but question 6 were significantly better in the post-test. In the control group, Q7 did not score significantly higher results in post-test.

Curiously, in both groups, the question that had a greater improvement was Q4:

> *"Banana is a yellow fruit when illuminated by natural light. If we put it in a dark room, in which case the banana appears Black? When it is illuminated by...*
> *a) red light.*
> *b) green light.*
> *c) blue light.*
> *d) yellow light.*
> *e) Banana will never appear Black when is illuminated."*

The question that showed the biggest difference between groups was Q3, where the students had to recognize that Black, White and Grey are not considered colours.

Students' internal representations progression

After analysing the students' scientific understanding gain of the colour phenomena, it is also important to consider the progress of their internal representations during the formal instruction. Thus, in order to obtain an in-depth acquaintance of the students' conceptual understanding, each questionnaire was classified into five qualitative categories, that is, five possible internal representations, according to Table 3.

Questions Q2, Q3 and Q6 were not used in this classification. Q2 is a control question from which no conclusions can be drawn concerning the students' ideas; Q3 relates to black, grey and white not being considered colours (it's a question that not requires interpretation of the phenomena); Q6 refers to the inability of the visual system to perceive colour at low light intensities.

Students who answer correctly questions Q1, Q4, Q5 and Q7, belong to the group of internal representation A. Answers Q1a) and Q4e) can be assigned to categories D and E; but Q7a) or Q7d) correspond to category D, whereas Q7b) or Q7c) to category E. Students with B or C internal representations know that colour is not an intrinsic property of an object; but whereas those in the group of model C assume that lights and paints mix according to the same rules, those of model B recognize different rules of the two situations. Thus, answers Q7b) or Q7c) correspond to category C, and answers Q7a) or Q7d) to category B. Table 5 summarizes the previous information.

In Table 6, the number of students in each level (A, B, C, D and E) is displayed horizontally in the post-tests and vertically in pre-tests for both groups. Inside the dotted square is represented the number of students that changed their ideas between the two questionnaires in each condition. Thereby, the data on the diagonal (marked in bold) means no progression in the colour mental representations. The data bellow the diagonal implies students that improve in their understanding. Of the total of 454 students, 36 could not be identified in any of the internal representations because their pre/post-tests included contradictions or missing answers. So, we could associate 92% of the students in five internal representations with high internal consistency.

Table 5 – Categories and related issues in pre/post-tests

Categories	Question
E	Q1a) + Q4e) + Q7b) or Q7c)
D	Q1a) + Q4e) + Q7a) or Q7d)
C	Q7b) or Q7c)
B	Q7a) or Q7d)
A	Q1e) + Q4c) + Q5e) or Q7a)

Table 6 – Students' internal representations of colour phenomena in pre/post-tests and their understanding progression between the tests

		Pre-test	Post-test				
			A	B	C	D	E
			113	71	45	2	0
Experimental Group (N =231)	A	1	**1**	0	0	0	0
	B	94	49	**28**	17	0	0
	C	115	50	38	**25**	2	0
	D	10	7	1	2	**0**	0
	E	11	6	4	1	0	**0**
			31	77	73	4	2
Control Group (N=187)	A	1	**0**	1	0	0	0
	B	64	11	**27**	23	2	1
	C	90	9	39	**39**	2	1
	D	17	10	3	4	**0**	0
	E	15	1	7	7	0	**0**

According to Table 6, practically all the students showed, in the pre-tests, that their understanding at this subject was at an elementary level. C level was the most popular one in both groups.

Students' pre to post-instruction gains were substantial in both groups, indicating that a high number of students experienced progression in their internal representations. Although the teaching proved effective both in control and experimental groups, there were, nevertheless, important differences between them. In the control group, 48.7% of the students improved their understanding, 35.3% remained unchanged after the intervention and 16.0% regressed. In the experimental group, the results were more favourable: 68.4% experienced improvements in their conceptual understanding, 23.4% remained unchanged after the intervention and 7.4% regressed. These results are in line with the overall gains that were presented above.

In spite of the formal instruction being effective in both groups, there were dramatic differences between the two learning conditions. The ATC instruction was notably better in the teaching of colour: 48.9% of the students were able to learn the correct conceptual model during the intervention, while only 16.6% did so in the control group.

CONCLUSIONS

This study had dual goals; identifying students' internal insights in the colour phenomena and analysing its progression in two different learning environments: Traditional instruction vs. ATC instruction. The analysis of the literature suggested five internal representations, which was confirmed by the data analysed in this study. Researchers have alerted to the fact that students are capable of holding two or more inconsistent ideas about the same subject; nonetheless, we believe that in this case these five categories are truly independent.

The comparison of student scores suggests that students involved in this program completed the colour test with a significantly better grasp of colour phenomena than students who had a traditional teaching. Both instructions were able to improve students' conceptual understandings of colour; yet the results suggest that students can gain better understanding when they have the opportunity to use the ATC model in a collaborative environment through Lab stations model.

The results of this study also demonstrate that this pedagogical setting is more effective in promoting conceptual change than the traditional instruction. Thus, 48.9% of the students in the experimental group experienced the desired conceptual change, that is, were able to learn the correct model during the intervention, while in the control group only 16.6% did so. Further, 48.7% of the students in the control group experienced improvements in the conceptual model, whereas in the experimental group this percentage rose to 68.4%.

Pre-test sensitization is one of our main concerns in this study, since we can't know how its existence influenced the students' post-test results. However, there was a five months delay between pre and post-test, so we have no reason to assume that pre-tests biased the students' performance in post-test. On the other hand, both groups took the pre-tests. Perhaps, the main issue, when we compare these two learning environments, is teachers' influence. Although the teachers of both groups had more than ten years of experience, and no intentional bias was introduced in the choice of teachers of either group, it is not possible rule out some influence of this variable.

In this paper, we have also illustrated how physics education research can contribute to improve understanding of the colour phenomena, by presenting materials that can minimize the changes of triggering errors. The ATC model, the supporting documents, both for teacher training and for the class and the experimental activities of the lab stations, were also an important outcome of this project.

Finally, there is a gap between research findings on conceptual change and their application instructional practice. Although there are several studies of students' pre-conceptions in the colour teaching, effective teaching approaches to facilitate conceptual change are still lacking. We believe that this study provided a practical component of classroom work, contributing to reduce this gap between theory and practice.

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Appendix A. Colour test

This test was given to the students in the experimental and control groups before and after instruction on the colour phenomena.

1. Consider a green plant in daylight. If we put it in a dark room and focus a red light on it, what will happen?

(A) The plant remains green, because the colour of an object is a property of it.

(B) Since red is darker than green and dark colours cover light colours, the plant turns red.

(C) The colour of the light blends with the colour of the plant, and that causes the plant colour change.

(D) The light gives its colour to the object, so the plant turns from green to red.

(E) The plant is green because absorbs the other colours excluding green. So, in this case, the plant absorbs red and stays black.

2. During a theater scene, before the actors come on stage, two spotlights, one red and one green, were projected onto the same region of the stage. What colour resulted from the overlapping?

(A) Red

(B) Green

(C) Yellow

(D) Brown

(E) Black

Justify your choice.

3. Mention eight colours you know.

4. Banana is a yellow fruit when illuminated by natural light. If we put it in a dark room, in which case the banana appears black? When it is illuminated by ...

(A) Red light.

(B) Green light.

(C) Blue light.

(D) Yellow light.

(E) Banana will never appear black when is illuminated.

5. In a dark room, a flashlight emits blue light to a yellow pen. What colour is the shadow of the pen?

(A) Red

(B) Green

(C) Yellow

(D) Brown

(E) Black

6. "All cats are gray in the dark." Who never heard this expression? It means that at night all cats look the same and with a grayish colour. This is because ...

(A) the objects change colour when they are illuminated.

(B) at low intensities, our visual system does not perceive the colour.

(C) in the evening the objects are not illuminated so they get always gray.

(D) in the evening cats change colour.

(E) The statement is false. Cats have always the same colour, we just can't see them.

(F) in the night light is black, so the cats look like black.

7. Ann made two experiences. First, she mixed two watercolours, one red and one green, with a brush. After mixing the paints, she directed two spotlights, one red and one green, on the white wall in her house. What were the Ann's results?

(A) When she mixed the paints, Ann obtained brown, but when she mixed lights, obtained yellow.

(B) In both cases, Ann obtained the same colour but with different shades.

(C) In both cases, Anna obtained the same colour: brown.

(D) When she mixed the paints, Ann obtained brown, but when she mixed lights, she obtained cyan.

Appendix B. Detailed data on pre-tests results

This table shows the results of the pre-tests, in both groups, before the instruction.

Table 1 - Pre-tests' answer choices (%)

		Control Group	**Experimental Group**
Question 1	a)	19.1	12.0
	b)	12.3	10.8
	c)	**39.7**	**50.0**
	d)	9.3	13.2
	e)	19.1	12.8
Question 2	a)	3.4	4.0
	b)	3.9	0.8
	c)	**61.8**	**72.4**
	d)	13.7	16.0
	e)	15.2	6.8
Question 3	0	11.3	6.0
	1	25.5	25.6
	2	51.0	51.6
	3	8.3	13.2
Question 4	a)	8.8	4.8
	b)	9.3	3.6
	c)	9.3	12.0
	d)	6.4	6.0
	e)	**63.7**	**71.6**
Question 5	a)	3.9	3.6
	b)	**40.7**	**45.6**
	c)	9.8	8.0
	d)	7.4	4.0
	e)	**36.8**	**37.2**
Question 6	a)	7.8	2.8
	b)	**37.7**	**51.2**
	c)	13.7	9.6
	d)	5.9	2.4
	e)	25.0	28.4
	f)	9.3	4.8
Question 7	**a)**	**35.8**	**34.8**
	b)	**38.2**	**33.6**
	c)	15.7	19.2
	d)	9.3	11.2

Note: In Question 3, answers were classified according to whether Black, White and Gray were not mentioned as colours (0), or whether one (1), two (2) or all three (3) were mentioned. The most frequent answers are in bold.