Cultural Studies of Science Education (2020) 15:211–239
https://doi.org/10.1007/s11422-018-9901-1

ORIGINAL PAPER

The co-existence of cultural and school science models in indigenous Mexican teachers: the mixing colors case

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Received: 11 December 2015 / Accepted: 17 April 2017 / Published online: 21 May 2019

Abstract

This paper presents the development and structure of indigenous Nahua teachers' ideas about mixing colors, as well their ideas about colors derived from their traditions. For the scientific school knowledge, teachers answered two questionnaires and an interview regarding knowledge from their culture; they were interviewed outside school. This represents two different types of knowledge that were analyzed with a distinct methodology. Ideas referring to scientific knowledge were analyzed using the partial possible model, which states that the inferences and explanations used to describe a subject consist of constricting ideas, rules of correspondence and a set of phenomenological inferences about processes. With those components, we developed models to describe conceptions about mixing colors. The cultural analysis involves how colors are related to a Nahua cultural environment through stories and tales that add properties to colors depending on their effects on people. For the analysis, we used a model based on non-sequential functional mechanisms. In the school context, the results showed that teachers change from a conception that focuses on colors as entities that do not change and as properties of the object to the idea that color represents a quality of substances or objects that can be modified by mixing them. The cultural context analysis showed almost no influence from community cultural aspects over the teachers' conceptions about colors. We conclude that teachers generate independent constructions between school and cultural knowledge.

Keywords Science education · Indigenous teachers · Models · Conceptions

Resumen

En este trabajo se presenta el análisis del desarrollo y de la estructura de las ideas de profesores indígenas Nahua acerca de la mezcla de colores así como sus ideas sobre los colores derivadas de sus tradiciones. Para analizar el conocimiento que tienen desde la visión de la ciencia escolar, los profesores respondieron dos cuestionarios y se realizó una entrevista; para conocer su conocimiento sobre su cultura se realizaron entrevistas fuera del ambiente escolar. Estas dos clases de ideas representan dos tipos diferentes de conocimientos, mismos que fueron analizados con metodologías diferentes. Las ideas relativas al conocimiento científico escolar fueron analizadas utilizando los Modelos Parciales Posibles, que establecen que las inferencias y explicaciones utilizadas por las personas para describir un fenó-

Lead editor: C. El-Hani

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meno se estructuran con las relaciones entre los elementos de tres conjuntos; el conjunto de las ideas constrictoras, el de las reglas de correspondencia y el constituido por una serie de inferencias fenomenológicas sobre los procesos. Con estos componentes, se desarrollaron modelos para describir las concepciones que tienen los profesores acerca de la mezcla de colores. El análisis cultural implica cómo los colores se relacionan con su entorno cultural. Para su análisis se tomaron en cuenta las historias y cuentos sobre los colores en función de sus efectos sobre las personas. Para el análisis se utilizó un modelo basado en los mecanismos funcionales no secuenciales. En el contexto de la ciencia escolar, los resultados mostraron que los profesores parten de una concepción centrada en los colores como entidades que no cambian y como propiedades del objeto, a la idea del color como cualidad que se puede modificar mediante la mezcla de colores. El análisis del contexto cultural, no mostró tener influencia sobre las ideas de los profesores acerca de los procesos de mezcla de los colores. Llegamos a la conclusión de que los profesores generan construcciones independientes entre la escuela y el conocimiento cultural.

The study of science education within different cultural environments has grown into a diverse and complex field (McKinley 2007). One area of interest involves studies of teachers and students from indigenous communities showing that even after the development of specific programs that address the need of the population, there is an increasing rate of students who quit their studies, as students find education programs inadequate for their needs while experiencing continuing discrimination (Kitchen, Hodson and Cherubini 2011).

Most studies have been conducted in indigenous communities analyse educational difficulties as a lack of comprehension or low demand for scientific careers that require science education. Gloria Snively and John Corsiglia (2001) argued that learning Western science for indigenous students constitutes a trans-cultural learning experience, so modern science is just one of many sciences that have to be incorporated into a science classroom. However, considering traditional or indigenous knowledge as a form of scientific knowledge and its inclusion in school is debatable. Sandra Harding (1994) and Masakata Ogawa (1995), consider scientific knowledge to be determined by the social and cultural environment in which it is developed and, therefore, each culture or society generates equally valid science and scientific knowledge. On the other hand, the non-relativist inclusionists, such as William Stanley and Nancy Brickhouse (2001), although they consider the inclusion of traditional knowledge as acceptable, do not accept that it has the same validity as Western science. Glen Aikenhead (2001) argues that some students may experience difficulties because their adoption of Western science can be experienced as an attempt at assimilation into a foreign culture (p. 338). Many researchers focus on the need to bring together local and global knowledge systems in the development of culturally responsive schooling (Abrams, Taylor and Guo 2012). In some cases, indigenous cultural knowledge is viewed as threatened by the education in "Western science" (McKinley 1996). In general, these challenges have several repercussions for indigenous community students including low scores in standardized assessment, lower access to higher education and rejection of science.

In a culturally responsive approach, the research projects allow new developments by trying to involve cultural knowledge and scientific education within the classroom. Among the proposals, we find that of Huei Lee, Chiung-Fen Yen and Glen Aikenhead (2012), who developed a module for the comprehension of "Measuring Time" to be useful for our thinking. These researchers identified two cultural worldview perspectives on time the place-based cyclical time held by the Amis, and the universal rectilinear time presupposed by scientists. From the use of the designed activities, it was observed that the students refined their ideas in both perspectives, as well as developed an increased interest in their culture. Most of the research (mostly on hidden assumptions) considers all members of an indigenous community -including children- have a complete and uniform cultural knowledge that cannot be modified; therefore, there are no studies about the different levels of comprehension of native culture and learning problems of natural phenomena. In this regard, Angelina E. Castagno and Bryan M. Jones Brayboy (2008) emphasized the relevance of analyses of the aboriginal epistemologies.

Relative to the teacher formation for indigenous communities, Margaret Sutherland (2014) describes three main approaches to this process. The first of interest rot us she calls, Access-Oriented Science Teacher Education. Based on the unequal access to high level education, this approach supports the tutoring of teachers with programs that enhance the access to superior education by providing financial, health and family support services along with additional courses, tutorials and encouraging communication with community member.

Another approach, Culturally Relevant Approaches, or Culturally Responsive Schooling, orient most programs and research projects to teacher training in special programs in their native language to develop teachers as border crossers between indigenous worldviews and Western science. One of the main problems in this approach is that teachers that are not native to the indigenous communities do not understand the native culture, so their approach commonly is to incorporate modified schoolbooks and activities that integrate the native cultural knowledge from the community. The understanding of the community and their culture is fundamental to achieving this goal (Lee, Yen and Aikenhead 2012).

However, research on science education within indigenous communities also has shown that there is some difficulty integrating cultural knowledge and academic scientific knowledge (Kitchen, Hodson and Cherubini 2011) especially when teachers' understanding of their own culture and of science can be insufficient or poorly developed (Cochran-Smith, Davis and Fires 2004).

Some studies (Gallegos-Cazares, Flores-Camacho, Calderón-Canales, Perrusquia-Máximo and García-Rivera 2014) have shown that it is in the children's construction of diverse phenomenological processes that we see an independence between the school education and the cultural context. Such studies have theoretical support from the field of multi-representational theory where different, even contradictory representations, can coexist in individuals, such as in the case of children's and adults' conceptions about the nature of death (Astuti and Harris 2008) or illness and disease transmission (Legare and Gelman 2008).

Wondering about the relationship between teachers' native cultures and their teaching of science we find some answers from the work of Glen Aikenhead and Hisashi Otsuji (2000), who analyzed the ideas of American and Japanese teachers about the nature of their students' culture and the connection with science that is taught in school. Aikenhead and Otsuji noted that both groups of science teachers seemed oblivious to the cultural challenges experienced by both groups of students negotiating the intersections between everyday and science knowledge.

Building on the body of research noted here, this research paper focuses on: (1) the conceptual construction of school scientific knowledge by native indigenous teachers, more specifically, about the mixture of colors; (2) the relation between the school scientific knowledge and explanations of teachers and their cultural knowledge about colors; (3) the comparison of the results from 1 and 2 with children's ideas about the same topics obtained in a previous study (Gallegos-Cázares, Flores-Camacho, Calderón-Canales, Perrusquia-Máximo and García-Rivera 2014). This last objective stands on the assumption that teachers have a more profound cultural and scholarly knowledge than children from the same community.

The topic about colors and their mixture is one of the many topics of the national program of basic education, established by the Secretaría de Educación Pública [SEP] of México (2011). This program requires that second-year primary school students identify basic colors as the components of any other color of light and primary color as the components of any color for painting, along with some material properties. According to SEP, there should be at least a narrow understanding of light phenomena, such as dispersion, reflection and refraction, within the third and fourth year of primary school (2011). Moreover, colors and their processes have an important cultural meaning to the community where the present study was developed, allowing a deeper analysis of color construction and process understanding between a cultural and physical point of view.

In the next section, there will be a description about the characteristics and context of the studied sample, along with theoretical analysis. Within the methodological section, there will be a description of the intervention process, the sample, and the methodology used to gather information. Afterwards, there will be a presentation of results, discussion, comparison with children's ideas and conclusions.

The educational background of indigenous teachers in Mexico

In Mexico, education for indigenous communities has changed from being centered on literacy in Spanish, which involved almost no active participation of the indigenous communities, to a later focus on the development of a specific educational model for the indigenous population, trying to cover the educational needs of the indigenous population with a multicultural approach (García Segura 2004). At the moment, the current educational policy guarantees the right of every child to a basic education, acquiring the knowledge that will allow the development of new abilities and values that are necessary to achieve personal and family success (SEP 2011). A new education reform is in progress (SEP 2015) that reinforces the position of individual development with the main objective for "students to develop competences for life that enable them to construct their identity as democratic, critical and creative citizens that Mexican society requires in the twenty-first century." Even though it can be inferred that collective needs are considered, this is not explicit, and there is still a preponderance of individual needs over the collective ones. Although this main policy does not specifically mention indigenous education, there are current public school systems that involve educators, most of them from indigenous communities, that teach in the community language and understand the cultural context—The General Management for Indigenous Education (DGEI) is the institution in charge of this population and its work is about promoting actions to allow equal and general access to a quality education in a context of a diverse indigenous and migrant population. Its strategy consists in generating conditions for operating to develop a flexible, pertinent and relevant curriculum, to promote teaching practices that value intercultural relations, as well as to promote processes of teacher training (SEP 2015). Even though the new educational policies try to reduce the current educational gap, a fair and equal development between the dominant culture in the country and the indigenous communities, which present lower education and development levels, is still far from reality.

The distance between indigenous communities in the country, the diverse cultural patterns, the public and migration policies are some of the factors that influence access to education and its level among indigenous communities, affecting the education levels of the whole country. This educational delay among the indigenous population has its roots in the absence of a coherent educational approach that takes the diversity of language and socio-economic factors into consideration. Within the present academic system there are high rates of students that are constantly absent and a general lack of access to education. Many of the indigenous schools have a lack adequate teaching faculty, so one educator is expected to teach several groups from multiple levels and ages. The indigenous community schools constantly lack supplies and internal infrastructure placing them in severe disadvantage to public schools in other parts of the country (INEE 2007). In addition, as pointed out by Bruno Baronnet (2008), teachers from indigenous schools are the most poorly prepared and paid teachers in the educational system.

Most teachers of indigenous schools in Mexico are bilingual; they speak their indigenous language and Spanish. They also belong to the community where they work. However, their preparation is not specialized in educating bilingual children. Most of the teachers from this community were educated in the normal rural schools or by several induction courses, and of the very few that attend university most attend their local UPN (National Pedagogical University). The induction courses have only the objective of providing an introduction to teaching bilingual children in order to prepare them as bilingual teachers (Salmerón and Porras 2010) under the assumption that, because the educator knows an indigenous language and understands the community cultural background, he or she will be able to teach with minimal further education (Ríos and Caballero 2001).

From 2004, a strategy for indigenous teacher professionalization was implemented. It focused on teaching a specialization in intercultural and bilingual education. However, this specialization did not consider fundamental aspects of each teachers background including their facility with reading and writing in their indigenous language (Baronnet 2008). As a result children, and some teachers who do not write in their home language, were participants in this study.

Indigenous schools struggle to find teachers with educational backgrounds in the Natural Sciences and related topics (Ríos and Caballero 2001), leading to an educational shortage and great difficulty by children and teachers to understand science, which can be observed in the National Education Evaluations (ENLACE 2012).

Main characteristics of the community

In this study, the participants are bilingual teachers (Spanish–Nahuatl). They work as teachers in preschool and primary levels of education, within an indigenous multilevel program. They belong to the township of Cuautempan, located in the Sierra Norte of Puebla. In this community there are a large number of indigenous people and therefore a great cultural richness which includes diverse cultures such as the Náhuatl, Totonaca, Otomí and Tepehua (García 1987). Inhabitants of the communities where the schools are located are bilingual and just over 70% speak Nahuatl (Instituto Nacional de Estadística y Geografía [INEGI] 2010).

There is an issue of high poverty levels in this township, which has a population of 8497 inhabitants (INEGI 2010). The schools have only blackboards and chalk, along with some free schoolbooks given by the Secretaría de Educación Pública (SEP). The way of life within this community is agricultural.

In the township of Cuautempan, there are two types of schools, the Indigenous School and the General State School. Both of these are considered rural schools and have to teach according to the National Program of Education. However, the educational goals of indigenous schools are different. Although there is a recognition by the official programs on the importance of preserving the local culture, the main goal of an indigenous school, as previously said, is to teach Spanish as a main language rather than teaching other topics, such as science or their own culture.

The parents within the community have the perception that the state school has a better teaching level than the indigenous school. Parents prefer to send their children to state schools, hoping they will finish their primary education there, resulting in fast student mobility.

Research conducted by the Instituto Nacional para la Evaluación Educativa (INEE) (2007) notes that "…indigenous children have better learning experiences if they study in general elementary schools within rural areas" (2007a, p. 43). The same study established that the learning differences between the two types of schools do not depend on social or economic differences or even the school equipment. The main difference was the quality of the education provided by the teachers.

Knowledge about colors from an indigenous Nahua community

For the analyzed community, no anthropological study about the development of knowledge and beliefs on colors has been conducted. However, we can acknowledge that it is shared with the nearest community, Cuetzalan, located also in the Sierra Norte of Puebla and which shares the Cuautempan community's cultural, linguistic (Cuetzalan is also a Nahua community) and symbolic knowledge. Based on the research of Mario Alberto Castillo (1997), conducted there we can say that colors and their Nahuatl names are organized into five *basic* colors that correspond to the evolutionary state IV in Brent Berlin and Paul Kay's (1969) proposal. Basic Color Terms, which argues for cross-cultural universality of a fixed number of basic color terms. For these authors, there are seven stages in the evolution of the basic words for color. In stage I, the categories for colors are represented with just two words, white and black, whereas in stage VII, there are between eight and 11 words. Stage IV has five words. The main colors are black, white, red, green and yellow. There are also other colors that are direct descendants from the *basic* colors. Those colors are blue, orange and purple, which are also derived from nature and come from the designation of the sky, orange and wild cherry (dark purple fruit), respectively.

There are some other colors that come from objects, for example earth, grass, sand, and coyote, among others, being an extension of nature itself. For the Nahua culture, the color is not independent from the object but part of it. There are also compound colors in the Nahuatl language that come from the use of the words for two colors, such as "dark blue", "brownish green," "yellow orange," "red orange," "white blue" and "dark purple." There are also compound colors that represent the mixture of a color and an adjective, such as "burned red," "pale yellow," "dried green" and "strong red." Additionally, there are compound colors that come from the name of a color and a noun, such as "blue sky," "yellow earth" and "dark smoke" (Ferrer 2000; Castillo 2007).

The Nahuas from the region think that color can show more or less intensity depending on the amount of water it contains. Depending on the intensity, colors can be designed as "little," such as "little black," or as "overly," such as "overly red." The same denomination can refer to the saturation between colors and the one that becomes more noticeable, such as "very white".

Within this culture, the organization of colors depends on their tonality and their similarity to other colors. The group color formation can be arranged by "basic colors" or by their tonality. The organization of colors can be observed on their clothing and in the ornamentation of ceremonies and ritual acts. Another aspect that Nahuas use to classify colors is their brightness. For them, the brightest colors can be used and combined (without mixture) and represent happiness. Furthermore, the pale or serious colors cannot be combined and have little interest within their community (Castillo 1997).

There are tales and stories about the benefits or curses of colors. These tales are spread by verbal transmission. These tales and stories will be analyzed in order to know their influence on the notions of teachers about the mixture of colors.

Methods

Analysis elements

The information obtained within this study in relation to the ideas that teachers construct for interpreting and explaining properties and phenomenological processes with colors and the ideas or beliefs about colors they take from their cultural point of view are quite different. For the first subject, we present an analysis of phenomenological constructions and predictions on the process of color subtraction from teachers' representations. This implies the construction of conceptual conditions (initial conditions, constrictions) and functional relations (relations among variables that establish causal sequential mechanisms) that were developed by the teachers. The second subject involves how colors are related to their cultural context. They are based on stories and tales that add properties to colors depending on their effects on people. These ideas do not belong to a phenomenological event and have a different structure that needs other types of analysis in particular, non-causal sequential mechanisms. For this reason, there will be an incorporation of an ontological cultural analysis about colors based on the cultural structure. These analysis elements are the same used in previous research on children in order to have elements to compare (Gallegos-Cázares, Flores-Camacho, Calderón-Canales, Perrusquia-Máximo and García-Rivera 2014), and distinguish whether the construction in students and teachers takes place in a similar manner or if the differences in cultural mastery, assuming that teachers have a greater mastery, imply different constructions.

Analysis criteria for the stories and tales about the actions of colors

If we consider that culture is conceptualized as a group of distributed ideas expressed in a public form, and responses to certain types of practices and ways of acting by individuals of specific environments (Atran, Medin and Ross 2005), then it is necessary to know whether teachers construct a relationship between cultural and academic knowledge. We started from the consideration that diverse tales and stories, verbally expressed by the community, are an important cultural tradition with the main function of preserving ancestral knowledge (Montemayor 1999). Therefore, the tales and stories also belong to the conceptions and notions from the community teachers.

Some tales and stories that contain magical events have some similarities to religious ideas. The most important stand is that they are independent entities and sometimes incoherent with one another, stablishing the possibility of extraordinary events and actions that defy intuition (Boyer and Ramble 2001). Additionally, such stories describe events or actions that do not belong to specific reasons, causal phenomenological relations or any other type of physical restrictions. They are, as Pascal Boyer (1994) said, non-schematic structures. These tales and stories have an intuitive character that allows their effective transmission, blotting any argument that refuses them. People generally accept them as faithful. For example, a curse or good luck results from these non-schematic structures.

The cultural expressions and tales about colors and their effect on diverse entities, such as people, animals and plants, express certain violations over diverse domain concepts (Hirschfeld and Gelman 1994). As Pascal Boyer and Charles Ramble described (2001), those beliefs and tales generate expectations that go further than the information and contain certain characters that make it easier for the community to remember them.

To determine if the teachers' narratives belong to the tales and stories (community beliefs), it is useful to apply the Boyer and Ramble (2001) model. This model established certain criteria for a narrative to be accepted as tale or myth. Certain criteria must be met. The narrative should: (1) be a pointer to a particular domain concept; (2) be expressed in an explicit way in which the intuitive reasoning is violated in a specific event, either through the breach of an expected intuitive solution or the transfer of a story element to another element of another category; and (3) accomplish other intuitive expectations. These three conditions must be clearly recognizable. For example, the spirits are associated with a certain domain such as the mountain, the river or other location (first criteria). The action is expressed as a violation to intuition because it brings good or bad fortune to the characters (second criteria). There are some valid expectations such as the erosion of the mountains (third criteria).

Boyer (1994) explains through the cognitive model that the analyzed events and concepts, such as in tales and stories, are more important and relevant than other types of cultural information. The compliance of these three criteria, according to Boyer and Ramble, constitutes a template shared with other beliefs in diverse cultures and makes them to be easily transmitted and assumed as part of the community beliefs.

With this in mind, it is possible to consider tales and stories, specifically about colors, as analysis materials. They belong to the cultural model, being recognized, remembered and transmitted by the community. In addition, the consistent and coherent use of cultural ideas about colors will confirm that the teachers also share these ideas and can be considered cultural experts (Legare, Evans, Rosengren and Harris 2012).

Analyzing phenomenological expressions criteria about the color mixture process

Descriptions of color mixtures and physical process explanations, such as the subtraction of colors, are different from the explanations of stories and tales. They have as a main characteristic the creation of causal relations and functional mechanisms. These mechanisms allow the determination of different models that help with the creation of intuitive interpretations and inferences that do not violate any logical expectation in a scholarly or intuitive way.

The construction of models of physical phenomena that use intuitive ideas and establish relations that allow the creation of explanations and predictions can be analyzed from the Partial Possible Model as proposed by Fernando Flores and Leticia Gallegos (1998) and applied with children in an indigenous community (Gallegos-Cázares, Flores-Camacho, Calderón-Canales, Perrusquia-Máximo and García-Rivera 2014). Such an analysis proposal is inspired in the structure of scientific theories approach correspondent to the Structural Program or Structuralism that, as described by Wolfgang Balzer, C. Ulises Moulines and Joseph D. Sneed (1987), is an approximation based in set theory, for representing the structure of examples and/or models of scientific knowledge and its time development, based on the idea that significant or interesting examples of empiric science are better characterized as entities of theoretical models than as linguistic entities or phrases. This approximation is based on a semantic view in which theories are described in terms of mathematical model classes (French 2010).

The Partial Possible Model proposal is a less formal variation of the formal structure of Balzer, Moulines and Sneed (1987) adapted to describe the inferences and explanations from non-scientist expert subjects about their representation or comprehension of phenomena. It is a constituted model formed by two main sets of concepts or conceptions. The first of them is the constricting concepts (CC), that is, the constrictions or conditions that the phenomenological elements should satisfy and the second is the rules of correspondence (RC), that is, all types of relationships between phenomenological elements, concepts and conditions. There is also an application set (A) that represents any phenomena that can be described by the sets CC or RC. Both sets (CC and RC) and set A are constituted in a unique model (M). In this particular research and with the purpose of amplifying our proposal, we include the term constricting ideas (CI) instead of constricting concepts. This allows us to analyze the corresponding teachers' ideas without restrictions and without modifying the proposal or the partial possible model structure.

Constricting ideas (CI)

CIs are conceptions the people have as a basis for interpreting certain physical phenomena and that are used to make inferences. These conceptions are believed to be true by subjects and thus constitute a type of axiomatic framework; it is in this sense that the constrictor term is used. CI could be explicit or implicit (Pozo 2006). CI characteristics (1) include conceptions that subjects accept as basic suppositions, among which we can identify a good portion of their intuitive ideas; and (2) have two possible origins: (a) phenomenological, in general partial knowledge interpreted intuitively, which in turn originates the establishment of phenomenological relations such as the p-prims described by Andrea diSessa (1993); and (b) non-phenomenological, conceptualizations inferred by non-perceptible factors, like the idea that heat is a substance.

Rules of correspondence (RC)

RCs are the subjects' ideas that define specific relationships between variables or between phenomenological conditions and variables. Their characteristics include (1) relations of order and extension, as in the case of simple proportionality and relations of greater than or less than; and (2) relations of specificity of phenomenological conditions, such as in the case of determining when certain processes happen or under which of certain suppositions physical conditions are applied.

Applications (A)

A, is the set of all the interpretable ideas that come from the relation of CI elements to RC elements. It constitutes the phenomenological expressions *f,* which belong to the subject's expressions that enabled him or her to use explanations and predictions.

Models (M)

The M model is made by the sets CI and RC, along with their possible applications A that can be inferred from the inference [CI, RC] → A. This inference allows any f_x that belongs to the application set A to be the causal result from some CI_i conception, which comes from CI. This result will be related to a rule of correspondence RC_j, which comes from RC. This process is expressed by $[CI_i, RC_j] \rightarrow f_x$. The M model has then the possibility of explaining the subject's ideas by the use of causal relations.

It is necessary to emphasize that the people's conceptions belonging to sets CI and RC are not known beforehand and are obtained from subjects' intuitive ideas. In this work, models are built with the teachers' ideas and their relationship to mixed colors.

Intervention process

The intervention process with the teachers is divided into two steps: preparation and application of the educational proposal within the classrooms. As previously described, there is poor preparation with the indigenous community teachers on scientific topics, even if they belong to the national education program. This preparation deficiency (Ríos and Caballero 2001) is also observed and recognized for the community teachers. Because of this, the main agreement with the community to allow the research process was to complete a preparation process along with the application by community teachers with their students.

The base project for the elaboration of this research was the EduCienPre educational proposal (Gallegos-Cázares, Flores-Camacho and Calderón-Canales 2008, 2009). The educational proposal was adapted to the basic indigenous community teaching level, providing several guidelines and texts for teacher preparation. This educational proposal acknowledges that teachers, along with their students, need to build models and representations that help them explain the phenomenological events in their surroundings. This means allowing them to build several conceptual structures and causal relations that lead them to build functional models (Coll and Lajium 2011). From the perspective of this proposal, the development of such representations can be accomplished when there is a good relation among trainers (who will be the teachers), teachers (who will be the students) and the several activities designed for them.

The proposal is focused on an evidence/explanation process (Duschl and Grandy 2008). To support the relation and explanation constructions, it is recommended to not only use a certain material or activity in the teachers' preparation stage but also to use diverse materials and didactic sequences.

It must be noted that paint, filters, clay and primary colors were provided with the purpose that children and teachers establish a two-way relationship between the material and the learned concepts. By this, they can understand several phenomenological situations and explain them with flexibility. To support the structure of representational constructions within the intervention process, the activities counted with organizers (note booklets) that contain several notes, information, images and useful materials to help the learning process of model constructions and relations.

All the teachers in the study received training, which comprised an explanation of the proposal and its objectives, practical knowledge of the teaching sequences and support in science concepts.

Training was divided into several sessions during one week (6 h per day), and its purpose was for the teachers to familiarize themselves with the didactic sequence activities. This training was performed to promote an understanding of the scientific concepts related to light and observed colors, basic colors and wave superposition (addition process), primary colors and color subtraction process, and understanding of the reasons behind the activities sequence so that the teachers considered themselves an integral part of the activities. Every teacher had an activity book with all the elements necessary for classroom implementation and explanations on light, color, and the processes of color addition and subtraction. It is noteworthy that the entire topic was new to teachers; although the topic is in the curriculum, they had never covered it in the classroom. All of this was performed prior to the classroom implementation, where only the teacher carried out the activities, without any intervention by the research team.

During the teachers' preparation to work with color sequences, they used the same materials and completed the same activities that the students would do in the classroom, as described in Gallegos-Cázares, Flores-Camacho, Calderón-Canales, Perrusquia-Máximo and García-Rivera (2014). With this, they could observe the results of color mixture or the use of filters. They also took more precise data from the results that helped them complete their tasks.

A prior agreement with teachers was made about a time plan to film the activities. After approximately three months and once the intervention with students ended, the work with teachers was resumed to clear doubts and analyze ideas and explanations taken from their pupils.

In the preparation stage, special attention was paid to the cultural knowledge and cultural understanding about colors from the teachers. They were able to decide the moment, situation and which information would be relevant for the conceptual construction about colors for the students within their classes.

Subject sample

The subject sample consisted of 27 teachers who work at preschools (six teachers) and primary-level community schools (17 teachers) within Cuautempan. Additionally, four teachers work as technical pedagogical counsellors (ATP in Spanish); their main activity is the preparation of, and advice to schoolteachers. All the teachers are graduates, and the four ATP have a master's degree in education but none have a specialization in science education. The teaching experience of the sample is approximately 17 years on average; it should be noted that approximately 50% of the teachers have more than 21 years of teaching. This allows us to consider them experts on the school culture as much as the everyday cultural context.

The teachers work in multiple-grade indigenous modality schools. In this type of school, they must teach several education levels at the same time. Students and teachers from these schools are bilingual for the Nahuatl and Spanish languages and belong to the community. Table 1 shows the teachers' distribution by the educational level they teach and their gender.

Research design

During the training and before the teachers applied the proposal in class, there were two sessions held to identify the meanings and use of color in the teachers' cultural traditions. In these sessions, besides the argumentation of ideas about color mixing, teachers told stories and community tales related to some colors with special meaning. These tales allowed them to recover a cultural context about colors. In addition to the sessions, there were also interviews with some teachers. The main purpose was to ask them about their ideas of colors, based on their cultural context.

To register the sample subject constructions about the color mixing process from the school context, two questionnaires were used. The first one was applied before the preparation course (questionnaire QBI). Three months later, when teachers ended their work proposal to apply it with their students, they received the second questionnaire (questionnaire QAI). One year later, nine teachers from the subject sample were interviewed (five women and four men; three preschool teachers, two first-cycle teachers, two s-cycle teachers, one third-cycle teacher and one ATP). The time elapsed among questionnaire application and the interview was determined to avoid an immediate influence from classroom work to diminish the effect of memory of work in the classroom. This allowed teachers to settle their ideas and show some cultural context influence. Each interview was videotaped and transcribed for later analysis.

Instruments

Questionnaire before intervention (QBI)

The QBI is a questionnaire with 12 open questions about tasks related to mixing colors and the use of color filters. It has questions regarding, for example, the definition of colors and their identification. Most of the questions were related to the color mixing process, their explanations and expected results. The tasks (the same as in the previous children's study) for the use of colors and filters were blue–yellow, red–yellow, and blue–red. For example: If we mix a blue color with a red, which color will result? Why does the result turn out to be that color?

Questionnaire after intervention (QAI)

The QAI is a questionnaire with 16 open questions about the color combinations included on the pre-test. Also, included are questions that apply to the reversible process of color combination and questions about the combination of three colors. For example: A professor obtains an orange color by two different processes. Which colors does he/she use? If

Table 1 Distribution of teacher sample by teaching level and gender

Teaching level	Gender		Total
	Men	Women	
Preschool	1	6	7
First cycle	3	2	5
Second cycle	1	3	4
Third cycle	5	2	7
ATP	1	3	4
Total	11	16	27

ATP Technical pedagogical counsellors

yellow, blue and red filters are put together, which color results? Would I obtain the same result if I combine paintings of those colors? Why?

The reliability test on questionnaires (internal consistency) shows a Cronbach alfa $\alpha = 0.768$, VAR = 0.1 (SPSS). For validation of the results of the questionnaire and interview interpretation in both cultural and school context, each of the researchers analyzed the interviews using the established criteria. Later, in a work session, the different categorizations were compared to establish the accordance level. The percentage of accordance was not valued by criteria but there was a discussion when differences were found to reach an agreement.

Interviews

The interviews were semi-structured and 20–30 min in duration. Interview questions addressed topics such as the use of color filters and color combinations. Additionally, questions about color names in Nahuatl and Spanish languages, along with their symbolic meanings and organizing a chromatic circle, were included.

Results

To obtain relevant categories for the tales and stories and for the teachers' ideas about color and their mixing process, we analyzed the videotapes and transcriptions, selecting only the parts that gave relevant and interesting information. The information provided a way to determine the inferences and explanations that were made. We are following the considerations of Orit Parnafes and Andrea diSessa (2013) about the micro-genetic analysis of learning within these categories: focused-theory (cognitive characteristics from the tales, taking the cultural aspects and the physical process model construction that involves), fine grain (particular attention to the teachers' reasoning elaboration) and open consideration of relevant data aspects (categories obtained by the subjects' expressed ideas).

Results will be presented in two sections. The first section (I) will describe the results on the cultural context of the community. The second section (II) will describe the results on the school context.

Colors within the community cultural context

Some tales and explanations that teachers presented in the group during their preparation course will be presented within the next section. They were classified into three categories.

Color identifications according to common objects

Colors come from nature. For example, black and brown come from wool and yellow comes from certain plant pigments.

Case 1. Group session, R = researcher, T5 = teacher 5 from preschool, T8 = teacher 8 from first cycle (1°–2° grade).

> R: *Which are the most used colors? Where does this color come from*[1]*?*
> T8: … *I find the black and also the brown color that comes from the brown bovine. However, there are other colors such as yellow that come from wood and herbs that you can use. If you boil the wood along with white clothing, you will obtain yellow clothing by a natural pigmentation process.*
> R: *Have you ever considered mixing the colors, obtaining something else?*
> T5: *Combining is not the tendency. If it is red or black it should remain like that. I actually do not see a combination process when I try to mix the colors. However, when I combine white wool with brown wool I can see a color mixing. You can also watch this in nature, when the sheep have brown/white wool when it was expected to be brown or white.*

The teacher considers that colors come from nature and they cannot be combined. The only thing that could happen is that a color overlaps with the other, without a mixing process.

Negative effects from color

Colors are used for naming things and for pointing out negative actions or events that happen to people. The next story is an example:

The rainbow has negative effects over people.

Case 2. Group session, T11 = teacher 11, first cycle (1st–2nd grade); T18 = teacher 18, third cycle (5th–6th grade); T15 = teacher 15, second cycle (3rd–4th grade).

> T11: *Our forefathers said that when it is raining and a rainbow appears, it means that the rain will not stop. They also said that when a rainbow appears, no children should point at it. If they point at it, the fingers that the child used to point will rot away.*

During the group session, several teachers commented about the rainbow tales.

> T15*: It happened to me; it was no coincidence…I was in sixth grade when they told me not to point at the rainbow. Despite the warning, I did it, and then my fingers began to stain yellowish. My mother punished me because of my actions and had to file my nail. For this reason, I can tell that this tale is real and could happen to anyone who points their finger at a rainbow.*

[1] Interviewee's utterances were freely translated from Spanish into English by the authors.

R: *It seems to me that there is a great fear of the rainbow. Is there something else that could happen?*

T18: *Yes…even more, when a pregnant woman looks at the rainbow, her child might be born without a finger or something like that. It is prohibited that pregnant women look at the rainbow. When I was pregnant, my mother got worried; she does not know whether to believe in the tales or not. It is like there is some fear that comes from our grandparents' stories. She even tries to use some metal keys beside me to protect me in case of a rainbow. I think that even if society had already proved that these things do not happen, there remains a certain psychological fear in our society.*

These stories show ideas of how a rainbow can affect unborn children or affect people. In these examples, there are subjects who consider this tale true and others who doubt it.

Positive effects of colors

The color red protects people from diseases and provides good health. It has a social and symbolic function, as will be seen in the next examples.

Case 3. Group session, R = researcher T4 = teacher 4, preschool, T15 = teacher 15, second cycle (3°–4° grade)

R: *Could you tell us something about the meaning of colors within your culture?*

T4: *I would start telling about the use of colors, such as red. According to my mother, the color red can be used for protection of animals, eatable plants and herbs or even yourself. For example, for our own protection or a child, you have to put the amulet "deer eye"* (a large seed likened to an eye) *tying it up with a red ribbon, protecting the child or yourself from bad spirits. Additionally, the color red is used to protect cattle or goats not only from the bad spirits but for the protection of your products and even against the envy of people.*

R: *Where does this belief come from?*

T15: *It is a social practice that comes from generations. I could guess that it comes from the need of people for protection and everything that allows us to live. It makes a strong relation with plants and animals.*

As can be observed, the color red has a symbolic reference for protection; the color itself has a function sustained by the beliefs of the community, and there is no other color that can fulfill this function. It was impossible to discover the origin of this belief; however, it can be established that there is profound belief in this community conception. In Table 2, the tales and their categories are shown.

As can be seen, the teachers' tales and stories fulfil the conditions described by Boyer and Ramble (2001). As an example, we can consider beliefs such as *red protects you from diseases and ensures health and good harvest.* This tale shows clearly defined domain concepts: the tales show that color is a defined domain concept (first criteria); there is a violation of the intuition domain in which color has an influence over people (second criteria); accomplish other intuitive expectations, the color does not have any effect on objects, for example, red does not protect objects from breaking or the fact that colors cannot be seen in darkness, and so forth (third criterion). We can consider these tales as having the structure for being considered as traditional among the community.

Table 2 Described the teachers' tales from their cultural ideas about colors

Categories	Tales and histories of colors
Color identifications according to common objects	Colors come from nature. The lamb's wool has brown and black colors and it is used to produce covering material.
Negative effects from color	Cutting a purple flower makes you a dish breaker Pointing to a rainbow with the finger can provoke disease on the pointing finger If a pregnant woman looks at a rainbow, her child might be born without a finger If a pregnant woman finds herself in a place that is being painted, her baby will be born with a stained face
Positive effects of colors	Red brings protection from jealous people and some diseases and also brings health White flowers protect the spirits of dead people Black cures and re-establishes the soul

Colors in the school context

Color identification

In both questionnaires (QB1 and QA1), the teachers are asked to indicate the colors they know and identify the ones that result from various mixtures. It can be noted that colors such as yellow, blue and red—these are the primary colors for mixture, not the basic colors of light—are recognized by 100% of the teachers, before and after to the intervention process. The same happened with the secondary colors—purple, orange and green—in all grades.

Application set and rules of correspondence: the teachers' ideas about the color mixture

We will show below four cases that exemplify how to obtain set A from applications *f* and the set of corresponding rules RC. Obtained fragments from the questionnaires and interviews will also be shown.

Case 4. Questionnaire QBI, Q# = question number, T2 = teacher 2, preschool (all grades).

Q10: *Imagine that we gather together (one above the other) two filters (colored transparent plastics), one of blue and another yellow. What would happen?*

T2: *Color combinations.*

Q11: *In which color do you think the things would look like? Why?*

T2: *Of two colors, bicolor.*

In this case, teacher T2 answers that when the filters join they will produce a new combination of colors; therefore, the phenomenological elements (colors) under the action results in a color combination and then there is a first RC relationship (RC.1); in the second answer, the subject only describes that the result of the combination is that you can see two colors. That expression (of two colors, bicolor) constitutes the phenomenological observable or *f.1*. Resuming, this teacher presents the following:

RC.1: The colors can be combined, mixed or joined.

f.1: When the two colors are combined, you can see at the end the two colors.

Case 5. Questionnaire QBI, Q# = question number, T11 = teacher 11 (man), first cycle (grades 1–2).

Q4: *If we mix blue and yellow paints, which will be the resultant color? What color would it form?*
T11: *Royal Blue.*
Q5*: Why did it turn to this color?*
T11: *Blue and yellow were combined* (not meaning mixing)*, the blue stands out.*
Q6: *What color results from mixing blue and red paint?*
T11: *Navy blue.*
Q7: *Why?*
T11: *Because the blue color dominates over red*

Although the teacher answers that the colors are combined (RC.1), his answer about the resultant color is focused on the color that he considers dominates the other one (*f.2*). In summary, this teacher's argument is about:

RC.1: The colors can be combined, mixed or joined.

f.2: When the two colors are combined at the end you can observe only one of them.

Case 6. Interview, R = researcher, T4 = teacher 4, preschool (all grades).

R: *If we mix blue and yellow paints, how would the resultant paint look? What color would be formed?*

T4: *A new color appears and stays green.*

R: *Why did that color result?*

T4: *Because of the mixture between both colors; the blue is stronger and the yellow is lighter.*

Teacher T4 has the idea that the colors are combined (RC.1) and that there are stronger colors than others. This idea expresses another RC relationship between colors where some of them are stronger than others (RC.2), the explanation of the result of the combination is centered in that one color is stronger than the other. (*f.6*); however, there appears in the explanation the idea that the stronger colors are the reason for the change (*f.4*). Resuming, applying this idea, teacher argues the following:

RC.1: Colors can be combined, mixed or joined.

RC.2: There are stronger colors than others.

f.4: When the colors are combined, you can observe at the end which is the strongest because it predominates.

f.6: When the colors are mixed, you can observe at the end a different color (answers green, that is the correct result of the combination).

Case 8. Interview, R = researcher; T27 = teacher 27, ATP.

R: *Okay teacher, now, when you make this mix to obtain another color, there would be some colors that, as we saw, cannot all be obtained. However, if I mix this one with this (blue and red), does it seems closer to one than the other, or is it always going to be an intermediate color?*

T27: *No, because, for example, to obtain the tonality, it would depend on the amount that is added, of the proportion that is added, because if I mix the red with the blue to obtain purple, if I mix exactly the same amount, it turns into a darker mulberry, but if I add a little redder, it turns out to be a lighter color.*

R: *How is that?*

T27: *If I add a little bit more of blue, it turns into a darker tone.*

Teacher T27 assumes that the colors are mixed (RC.1) and the proportion of them is important to the final result (RC.3 y *f.9*). In summary, this teacher argues the following:

RC.1: Colors can be combined, mixed or joined.

RC.3: The resulting color of the mixture depends on the ratio or amount of the mixed colors.

f.10: Different proportions of color give different shades or intensities of the resultant color.

Table 3 shows the set of relations RC and the phenomenological appliances *f* that appeared in the questionnaires and interviews.

We observed the relation with a correspondence rule determines the phenomenological expressions or applications that the teachers express. Thereby, *f.1* when two colors are combined at the end, you can observe both colors, has applied to RC.1, the colors can be combined or joined, independently from the action result. Thus, we can say that when the teachers express one sentence, this can be characterized by [RC.1; *f.1*]. When shown as more than a correspondence rule, it is expressed as [RC.1, RC.2; *f.4*]. Table 4 shows the percentage of occurrence of these relationships.

As shown, expressions *f.1, f.2, f.3* and *f.5*, only appear on the questionnaire QBI, which implies a change in the recognition that from two colors you can obtain a third one. It is observed that the argument of the color strength (RC.2) to explain the color combinations increases in QAI for first-cycle teachers, decreases for preschool and third-cycle teachers, and remains the same for the second-cycle and ATP teachers.

When appearing in the inference RC.2 and *f.4*, the idea that the colors are not mixed is implied in their arguments, whereas if RC.2 appears by itself, the teachers recognize the possibility of mixture colors, even though only one of the colors will be observed. This appears in all respondents except in the first-cycle teachers.

The expressions [RC.1; *f.6*], [RC.1; *f.7*], [RC.1; *f.8*], [RC.1; *f.9*] and [RC.1, RC.3; *f.10*], based on the idea that colors can be mixed, increase in the questionnaire QAI; [RC.1; *f.6*] has the highest percentage (on average 95.5) and is also found in the interview, which indicates that the majority of the teachers reached a change.

Correlatively, you can find a relation [RC.1; *f.8*] and notice that the inverse process appears only on QAI; however, it does not appear generalized in the interview (with the exception of the two last cycles).

Table 3 Lists of RCs relations and phenomenological expression of teachers

Correspondence Rules (RC)	Phenomenological expressions (*f*)
RC.1 Color substances can be combined or be together RC.2 Some colors are stronger than others RC.3 The resulting color of the mixture depends on the ratio or amount of the mixed colors	*f.1* When two colors are combined, at the end, you can observe both colors *f.2* When two colors are combined, at the end, you can observe only one of them *f.3* When the colors are combined, at the end, you can observe the one that remains on top *f.4* When the colors are combined, at the end, you can observe that the strongest is the one that predominates *f.5* When the colors are combined, at the end, you observe the most weak or transparent *f.6* When the colors are combined, at the end, you can observe a different color (correct) *f.7* When the colors are mixed, at the end, you can observe a different color (incorrect) *f.8* The color observed is the result of the mixture of the other colors (inverse correct) *f.9* The color observed is the result of the mix of other colors (inverse incorrect) *f.10* Different proportions of color give different hues or intensities of the resulting color

This result could be related to the activities carried out with students, where there were few opportunities to address the prediction of the colors that make up a given third color. It also considered the fact that the expressions [RC.1, RC.3; *f.10*] also increase, by a smaller percentage in both QAI and the interview, implying that, for the teachers, there are still problems in understanding the proportionality of the colors in the color resulting from the mixture.

The inferences [RC.1; *f.7*] and [RC.1; *f.9*], which implied the combination idea, but without which teachers can correctly predict the resulting color, decreased in general, but were not removed as is observed in the interviews.

Discussion

If we take as a starting point the premise that a mental model is the product of a cognitive process that involves sectioning a part of what is being observed as partial descriptors (Treagust, Chittleborough and Mamiala 2002) and expresses a set of relations that use a causal and functional operation to explain natural phenomena (Flores and Gallegos 1998), then the relations established by the teachers provide elements to establish a set of relations that represent the process of color mixing. These may constitute models and can determine whether there are changes in their explanations and descriptions.

To explain teachers' cognitive constructions from the framework of the models, there is a need to establish the CIs and their causal inference relations. From all the obtained data, we observed that there are two main sets of applications or phenomenological explanations. One establishes that the combinations of color do not produce a different color (*f.1, f.2, f.3, f.4, f.5*). The other explanation establishes that the combination of two or more

Table 4 Percentage of phenomenological expressions on the pre-test and post-test questionnaires and during the interview with teachers

Phenomenological expressions	QBI					QAI					Interview				
	P	C1	C2	C3	ATP	P	C1	C2	C3	ATP	P	C1	C2	C3	ATP
[RC.1; *f.1*]	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[RC.1; *f.2*]	71	40	50	71	25	0	0	0	0	0	0	0	0	0	0
[RC.1; *f.3*]	14	0	0	14	0	0	0	0	0	0	0	0	0	0	0
[RC.1, RC.2; *f.4*]	71	100	100	86	25	57	40	100	43	25	33	0	50	100	100
[RC.1, RC.2; *f.5*]	14	0	25	29	0	0	0	0	0	0	0	0	0	0	0
[RC.1; *f.6*]	100	80	100	100	100	86	100	100	100	100	67	100	100	100	100
[RC.1; *f.7*]	86	100	50	57	75	29	0	25	71	50	33	50	50	100	0
[RC.1; *f.8*]	0	0	0	0	0	86	100	100	86	75	0	0	50	0	100
[RC.1; *f.9*]	0	0	50	0	0	14	0	0	14	25	33	0	50	100	0
[RC.1, RC.3; *f.10*]	0	0	50	0	0	43	20	50	57	0	33	20	50	0	100

Percentage of teachers who expressed that relation at least one time (QBI before the intervention; QAI After the intervention; P Preschool; C1 Cycle 1; C2 Cycle 2; C3 Cycle 3; ATP Technical pedagogical counsellors) colors produce a different color (*f.5, f.6, f.7, f.8, f.9, f.10*); however, the expected result was not always correct (*f.7, f.9*). From the first set, it is possible to infer that the color conception is strongly related and attached to substances, and object conditions that are found in their environment (Anderson and Smith 1986), creating an ideological challenge that cannot be modified, which can be expressed as *CI.1 Colors are entities that do not change*, corresponding to the first set of proposals. In turn, from the second set, it can be inferred that colors are only some qualities from substances or objects but not dependent on them; this provokes the idea that color can change; *CI.2 Colors are modifiable qualities,* corresponding to the second proposal set. It is important to notice that the constricting ideas *CI.1* and *CI.2* are only expressed by the joint analysis of all the participants' ideas and not from one or two cases.

To exemplify how teachers make their inferences with CI, RC and *f*, reconsider Case 2, in which a teacher of the first cycle told us:

R: *If we mix blue color with yellow color, which will be the color of the resulting paint? Which color will be obtained?*

T2: *Royal blue*

R: *Why that color?*

T2: *When blue and yellow are combined, the blue color highlights more.*

R: *If we mix some blue paint with a red one, which color will be obtained?*

T2: *Navy blue*

R: *Why that color?*

T2: *Because blue color dominates*

From this section, one can recognize that for this teacher colors do not change, the predicted blue color (dominant color) is not affected by the yellow and red colors; therefore, there is no alteration to the dominant color if you are seeking to obtain a secondary color (CI.1); then, the next action is to combine them (RC.1). However, as there is no mixture, only one of the colors can be observed (*f.2*), which can be expressed as [CI.1; RC.1] → *f.2*

The inference set belongs to diverse models that establish how teachers build their predictions and explanations depending on the color combination process. Responses from the questionnaire and interviews reveal two main models: M1 explains an absence of change after color combination, and M2 explains that color combination can produce a new color, but the predicted color cannot always be correctly predicted. The models contradict one another, considering that CI.1 and CI.2 are a denial of one another. Models M1 and M2 are expressed in Table 5.

In model M2, the application set can be clearly differentiated where teachers made a correct prediction of the resulting colors and the ones who did not make a correct prediction. The correct usage of this model lies in the initial color recognition condition. By this consideration, another subset from M2 can be created, considering only the correct color inferences and established as M2c = ([CI.2; RC.1] → *f.6*; [CI.2; RC.1] → *f.8*; [CI.1; RC.1, RC3] → *f.10*) and a subset M2i = ([CI.2; RC.1] → *f.7*; [CI.2; RC.1] → *f.9*) that describes the incorrect inferences about the resulting color.

Table 6 shows models M1 and M2 applied to every teacher. Teachers from preschool: T1–T7; teachers from the first cycle: T8–T12; teachers from the second cycle: T13–T16; teachers from the third cycle: T17–T23; and teachers ATP: T24–T27.

Table 5 M1 and M2 models

Models	Model components
M1	[CI.1; RC.1] → *f.1*
	[CI.1; RC.1] → *f.2*
	[CI.1; RC.1] → *f.3*
	[CI.1; RC.1, RC.2] → *f.4*
	[CI.1; RC.1, RC.2] → *f.5*
M2	[CI.2; RC.1] → *f.6*
	[CI.2; RC.1] → *f.7*
	[CI.2; RC.1] → *f.8*
	[CI.2; RC.1] → *f.9*
	[CI.2; RC.1, RC.3] → *f.10*

As Table 6 shows, teachers use both models (except two teachers of the sample who use only M2c) before the intervention process. The use of diverse models, even contradictory ones, is not unusual and has been observed in elsewhere, for example, studies with children (Legare, Evans, Rosengren and Harris 2012); the results depend on diverse factors associated with the specific context and the questioning process. Significantly, during the first questionnaire (QBI), most of the teachers use both models (92.6%) and most of them do not identify all the mixed colors (except for T7 and T25). In the questionnaire after the intervention (QAI), the situation is different; the teachers demonstrate a tendency to use M2, and in particular, the use of M2c is high (48.2%), with 33.3% of teachers only using M2c. In preschool, three teachers use the M2 (T1, T2, T3) and the other teachers use both models, with a preference towards M2c. Among first-cycle teachers, three of them only use M2 (T9, T10 and T11) and the rest use both models but prefer the M2c model. In the second cycle, the four teachers (T13, T14, T15 and T16) mainly use M2c.

In the third cycle and ATP teachers, four teachers changed the M1 model to the M2 (T18, T19, T22, T24) and the other teachers did not change completely from one model to another, except the teachers who use model M2 all the time (T17, T25, T27). However, they increase the use of the M2c model. Some teachers still find it difficult to predict and identify some colors such as purple, orange, green and other colors such as brown.

Only T1, T3, T9, T10, T11, T18, T19, T24 and T27 identify every color and change their inference model to M2. Similar results were observed in the interview analysis, in which teachers change to the M2 model. Nine teachers (33.3%) who change to the M2 model on QAI lost phenomenological expressions in QBI such as *f.4*. The other 14 teachers (51.8%) who maintain the coexistence between the M1 and M2 models continue using *f.4* as a result of the M1 model. The idea of certain color strengths is important to understand the transformation process.

What is the relationship between the teacher's model construction and their cultural conceptions?

To analyze the possible relation between the development of the color mixing process cognition and the culture-imposed cognitive conditions, it is necessary to analyze the transformation of teachers' ideas about color and the possibility of activities that allow an

Table 6 Use of models M1 and M2 by teacher (T is for teacher)

Teaching level	T	QBI	QAI
Preschool	1	M1–M2	M2c
	2	M1 > M2	M2
	3	M1 < M2	M2c
	4	M1 > M2	M1 < M2c
	5	M1–M2	M1 < M2c
	6	M1 > M2	M1 < M2i
	7	M2c	M1 < M2c
Cycle 1	8	M1–M2	M1 < M2c
	9	M1 < M2	M2c
	10	M1 < M2	M2c
	11	M1 > M2i	M2c
	12	M1 < M2	M1 < M2c
Cycle 2	13	M1 > M2c	M1 < M2c
	14	M1 > M2c	M1 < M2c
	15	M1–M2	M1 < M2c
	16	M1 < *M*2	M1 < M2c
Cycle 3	17	M2	M2
	18	M1–M2	M2c
	19	M1-M2	M2c
	20	M1 > M2c	M1 < M2
	21	M1 > M2c	M1 < *M*2
	22	M1–M2	M2
	23	M1 > M2c	M1 < *M*2
ATP	24	M1–M2	M2c
	25	M2c	M2
	26	M2	M1 < *M*2
	27	M2	M2c

QBI Questionnaire before intervention, *QAI* questionnaire after intervention, M2 means use M2c or M2i in same proportion; ATP Technical pedagogical counsellor

afterthought about the physical processes of colors. Once this construction is built, it is possible to establish some links. These contain two different aspects over the cultural context. The first aspect (a) is the influence of tales and stories on the colors that belong to their cultural context. The second aspect (b) refers to the relation of the process with the elements obtained within the anthropological analysis.

An element that stands out is that teachers, who were educated from Normal Schools and even from the Pedagogical University, presented on their QBI the idea that colors cannot be mixed (CI.1). This is surprising, because most of the teacher formation focus on basic education and preschool education. Both educational levels require particular attention to the understanding of color and the development of activities with them.

As a second aspect, from the idea of transformation process from the correspondent ideas CI.2, there is recognition from the teachers that color combination is possible, and therefore, there is a change from the use of model M1 to model M2. When the teachers change their conception of colors from M1 to M2 models, they shift from viewing color as a concrete object to conceiving a transformative process, thereby reaching a culturally scientific understanding of the physical process of color subtraction (light absorption); this only happens on 44.4% of the subject sample (9/16 women and 5/11 men). However, almost all the sample (92.6%) uses the M2 model, even if it is in a shared way with the M1 model. This implies that, for the teachers, there is an unclear difference between both conceptions; therefore, their inferences depend on specific color mixtures rather than a shared appreciation for what happened when colors are mixed together. Additionally, as happens in studies with children, not all the teachers have a complete recognition of all the colors that can be obtained from the combination of primary colors as laid out scientifically.

How should we understand the results from their cultural context?

From the analysis of tales and stories, we could find no relation between the tales and teachers' present cultural context. For example, red has protective attributes that are highly recognized by the community. However, it does not have any particular role in the building of color mixing models M1 and M2, being only considered a "strong" color. The same thing happens with purple or any other "strong" color. For example, within the questionnaires or the interviews, there were no data that refer to the fear people have of mixing several colors of the chromatic circle, which contain the colors of the rainbow. We can say that the tales are independent from the ideas in the school context. Other studies in diverse academic fields yielded similar results (Gutiérrez and Rogoff 2003).

However, independence from the cultural context seems unclear when we take account of the cultural ideas of classification and origins from colors, obtained from historical and anthropological studies (Castillo 1997; Ferrer 2000). The idea of color as an object or entity transcends the ontological idea of color from this indigenous community, as it also belongs to other cultures. This idea can be observed in several studies with children (Anderson and Smith 1986) and agrees with Boyer and Ramble's (2001) findings. These findings suggest that there are frequent structural elements associated with how people react to colors across several cultures. Besides, it concurs with the proposal of Annette Karmiloff-Smith (1992) explaining that the implicit conceptions of subjects give structure or guide their thinking about physical phenomena, implying that it is not a specific culture that establishes that way of thinking; therefore, it can be said that the M1 model is an independent construction. The hypothesis here is that implicit ideas (or even phenomenological primitives) (diSessa 1993) about the physical interpretation of basic phenomena constitute the basis on which people built explanations about observed phenomena such as color mixing, independent of other representations or even cultural traditions.

How are teachers' results compared to those of their students?

Relative to the color mixing process, teachers and their pupils constructed the same models, M1 and M2. Likewise, before the intervention process, in both populations, both models are used in equivalent proportions.

Differently from the pupils who mostly transit from M1 to M2, in teachers both models retain their connection to a specific model even after they have instructed the activities proposed in the intervention in accordance to model M2. This points to the idea that color as an object is more deeply rooted continuing to appear in teachers' explanations suggesting that they do not recognize the difference between their ideas and those about which they are learning.

About the cultural elements, teachers and students share the stories and tales they know about colors, but these are more diverse in teachers, suggesting a greater diversity of cultural knowledge for teachers than children.

It is possible to see a difference: in teachers, those stories and tales are related to personal or indirect life experiences. So, teachers tell about happenings in their or another individual's life (in a positive or negative sense).

In both instances, cultural elements, in terms of stories and tales, do not influence the construction made by children and teachers on the processes of mixing of colors. The explanations made in the school context are centered on their ideas about the phenomenology and when the context is outside the school the stories appear, but connections between them, were not were not observed.

Conclusions

From the obtained results, we consider that some folk aspects of indigenous culture, even the more noticeable aspects such as tales and stories, in which their own structures have some characteristics against intuition (Boyer and Ramble 2001), have no influence on new learning or constructions in children and teachers on the issue (color mixing) discussed in this study. With the mixed colors, notions were defined by two models M1 and M2, both use constricting ideas that proceed from two ontological natures, the color as object (M1) and as a quality (M2). This implies that cultural influence cannot be considered the main affecting reason for the construction process or explanations about some themes of basic physical phenomena in this particular context.

Nevertheless, other cultural elements related to ontological issues, such as the nature of color as an object or determined by objects, in those who are more deeply-rooted in the indigenous culture, seems to interact with a change towards other kinds of explanations with a different ontology. Although the idea of color as an object or inherent to objects is not particular to the Nahuatl culture, as shown by studies on children of other cultural contexts, as it is a part of the indigenous culture, and a relevant conception for this study. To explain this permanence, the main hypothesis is that the implicit conceptions (Karmiloff-Smith 1992), basic phenomenological constructions (diSessa 1993) and the phenomenological context dependence (Flores and Gallegos 1998) are the elements on which people make representations about some natural phenomena. This will require a new specific analysis and the development of new research.

Additionally, we notice that both types of knowledge (scholar and cultural) are coexist as independent aspects in each person, presenting valid multicultural constructions on their corresponding context, being accordant to the epistemological profiles proposed by Gaston Bachelard (1968).

We consider that the schooling process needs to strengthen both perspectives, as in the culturally responsive schooling approach, but always specifying their differences. For example, it is important that teachers from the analyzed community have more references of their color ideas and classifications. In this way, a clear recognition for their different context and for the influence of each in daily, professional and scholarly life will allow them to see academic knowledge as the "other point of view" and not as a knowledge substitution that replaces any other way of knowledge as has been proposed by several researchers as Snively and Corsiglia (2001) and more recently Mack et al. (2012).

Acknowledgements The authors wish to thank Héctor Covarrubias Martínez, for his support and comments on the performance of this work.

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