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Impact of the Use of a Teaching Toolbox in an Awareness Campaign on Children's Representations of Coral Reefs

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Environmental education for children is one of the fundamental tools required to reverse the degradation of our environment and the biodiversity erosion. Currently coral reefs are part of the vulnerable ecosystems which are most threatened by human activities and climate change. Responding to these pressures demands decisions at multiple scales, based on solid knowledge of coral reefs but also on strengthened awareness to build adaptive management solutions. Here we evaluate the impact of an environmental awareness campaign for children using a teaching toolbox developed by scientists (MARECO "The Coral Reef In Our Hands"). To assess this impact before and after using the toolbox, we analyzed the evolution of children's representations of coral reefs through drawings. This study was carried out in New Caledonia, focusing on five elementary schools in different social and cultural contexts (urban, rural and coastal). Two hundred and forty-eight drawings were made by children. The drawings were analyzed quantitatively using multivariate statistical analyses which reveals a diversity of representations in children with diverse sociocultural profiles, but also between schools, emphasizing that relationships with nature and marine environment vary according to direct and indirect experiences related to reefs. Furthermore, our results pointed out relevant differences in coral reef representations before and after the use of MARECO, particularly regarding their knowledge of reef biodiversity associated with multicolored organisms and the connection of coral reef with environment, the number of colors being used as a proxy of this holistic vision developed by children. These results point out the performance of MARECO as a playful tool to transfer scientific knowledge to children. Coral reef conservation is intimately linked to an awareness in young generations of the environmental challenges of tomorrow. To be agents of change in a sustainable world, children must be engaged in a fun, rigorous, action-oriented and socially responsible learning process such as the ones developed in participatory approaches.

Keywords: coral reefs, biodiversity, interdisciplinarity, environmental education, children drawings, representation, color variable, New Caledonia

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INTRODUCTION

The Anthropocene accentuated the rift between humankind and nature, accelerating the degradation of our environment and the biodiversity crisis (Steffen et al., 2011) without there being any major solutions at the present time (Carrière et al., 2013). Restoring better balance to the relationship between humans and nature firstly requires improving knowledge of nature and the links connecting living beings to their environment. For this, environmental education is one of the fundamental tools required to reverse the current trends in biodiversity loss but whose role remains underestimated and, as a consequence, still currently underused (Feinsinger, 1987; Brewer, 2002; Ballouard et al., 2011). In 2015, the international community recognized, through the 2030 Agenda for Sustainable Development, that education (SDG 4: ensure inclusive and equitable quality education) was essential for the success of all 17 of its goals, including SDG 14 (conserve and sustainably use the oceans, seas and marine resources for sustainable development) which includes the sustainable development of coral reefs.

Coral reefs are the most diverse marine ecosystem on Earth (Veron, 1995; Bellwood and Hughes, 2001; Paulay, 2017) and their biological, ecological, cultural and economic benefits are widely recognized (Moberg and Folke, 1999). They are charismatic ecosystems, with their esthetic value being a strong argument for conservation, a lever of communication, a factor of human well-being and an opportunity to reconnect humans to their environment (Tribot, 2017). Although some remote unpopulated wilderness areas remain in very good condition (Graham and McClanahan, 2013; Chabanet et al., 2015), an estimated 19% of the world's coral reefs have been lost and a further 35% are seriously threatened (Wilkinson, 2008; Veron et al., 2009; Burke et al., 2012). As a result, one-third of all reef-building corals are considered to be at risk of extinction (Carpenter et al., 2008). One of the main causes of coral reef degradation over the past decades is worldwide demographic growth and socio-economic development, which are often accompanied by overfishing, sedimentation from urban development, eutrophication, marine pollution, and coral diseases (Hughes et al., 2003; Hoegh-Guldberg et al., 2007; Newton et al., 2007; Veron et al., 2009; Johnson et al., 2013; Séré et al., 2015), but also the increase of recreational users in coastal areas (Gonson et al., 2016, 2017). Anthropogenic disturbances on coral reefs make them much more susceptible to current and future climate change (Hughes et al., 2017), particularly with the increase of mass bleaching events (Spalding and Brown, 2015; Heron et al., 2016; Hughes et al., 2018) and ocean acidification (Schönberg et al., 2017; Eyre et al., 2018; Wu et al., 2018). These changes have a significant impact on the welfare and livelihoods of over 500 million people worldwide, mainly in the Southern countries, where they depend directly on these ecosystems and the goods and services they provide (Moberg and Folke, 1999). The management of coral reef ecosystems is therefore critical, both ecologically and socially. Sustainability of coral reef ecosystems involves multi-level decision-making processes based on solid scientific knowledge of coral reefs' socio-ecological systems as well as empirical local ecological knowledge and observation within the environment that constitute pertinent indicators of socio-environmental changes (Sabinot and Lescureux, 2018). It must also involve education of local populations including children to enable them to understand critical issues associated with the importance of coral reefs, so they can become enlightened citizens engaged in the sustainability of the latter.

In 2010, recognizing the lack of links between science and society, a team of women (coral reef scientists, an educationalist, a nature artist, a graphic designer and an elementary-school teacher) developed the teaching toolbox MARECO, "The Coral Reef In Our Hands," which includes educational games. Created with the goal of transferring the results of research on coral reefs, the toolbox aims first and foremost at raising awareness and educating younger generations about reef biodiversity, the disturbance of coral ecosystems and the need for management through cooperation between actors (co-management). Childhood (5–11 years) was targeted as the key period for introducing environmental education effectively owing to the strength and lasting quality of an early relationship formed between children and the natural world (Caro et al., 1994; Rivas and Owens, 1999). The toolbox has been used in some schools in the Indo-Pacific (Vanuatu, New Caledonia, Reunion, Mayotte and Madagascar).

In 2014, an interdisciplinary team of researchers (ethno-ecologists, environmental anthropologists, and biologists) engaged a new research program in social and natural sciences around coral reef issues. This program combined an awareness campaign using the MARECO toolbox and an innovative approach based on children's drawings to document children's ecological knowledge. It has been conducted in four French territories (New Caledonia, Reunion, Mayotte, Southern France) targeting twenty elementary schools (1st and 2nd grades) in contrasted social and cultural contexts. Based on ethno-ecological and anthropological approaches (Berlin et al., 1973; Toledo, 1992; Ellen, 1993; Ingold, 2004), combined with social representation theory (Moscovici, 2003) applied to environmental sciences, the overall aim of the scientific program was to study children's representations and knowledge, and uses of coral reefs through drawings. Like Doise and Garnier (2002), we consider that social representation theory enables the exploration of the interactions and positions that social groups have (here, children in different schools) relative to social objects of varying complexity (here, coastal marine ecosystems, and more particularly the coral reef). The social representations correspond to opinions specific to a culture, a social class or a group relative to social environment objects (Moliner et al., 2002). As drawings are connected to the so-called "visual realism" when children "draw what they know" (Luquet, 1927), we seek to study through drawings how children from different sites and cultural environments perceive and live in their "nature" (Pagezy et al., 2010; Calandra, 2013; Sabinot and Carrière, 2015; Carrière et al., 2017), and how their experience, knowledge, perceptions and beliefs are shaping these ways of conceiving and dwelling with their "nature" (Ingold, 2004).

Here we evaluate the effect of an environmental awareness campaign on children through the changes in representations after using the coral reef teaching toolbox. More precisely, we seek to assess how and to what extent this specific campaign in school influences the drawing representations of the coral reef, particularly in terms of marine biodiversity, and interactions of species in the ecosystem, including with humans.

Three hypotheses will be tested:

1- The groups of children in the different schools (with contrasting natural and socio-cultural environments) have specific representations of the marine ecosystems (sea or coral reef).
2- The number of colors used by the child for the drawings can be used as an indicator that the child has developed a holistic perception of the sea or coral reef.
3- The impact of MARECO is assessed on the basis that the child has developed a holistic representation of the coral reef, combining (i) diversity of colors (perceived diversity of species) to a healthy reef, (ii) human activities to the coral reef ecosystem; and (iii) coral reefs to their environment.

This paper presents the findings obtained from our field site in New Caledonia, a UNESCO World Heritage site, and one of the most well-known French coral reefs.

MATERIALS AND METHODS

Study Sites

New Caledonia is a French overseas collectivity located in the southwest Pacific Ocean, approximately 1,500 km off Eastern Australia (**Figure 1**). The archipelago as a whole has a land area of 18,600 km^2 for a population of 269,000 inhabitants (INSEE, 2014). The population of New Caledonia is young, in a country where the GDP (Gross Domestic Product) is one of the highest in the Pacific region but with major socio-economic disparities according to the various urban and rural zones (IEOM, 2008), in particular regarding the educational system and the employment market. New Caledonia is also characterized by high cultural diversity: for more than one, sometimes two centuries, European, Oceanian and Asian people have been living with Kanaks who represent 39% of the population today (INSEE, 2014). This leads to inequalities in terms of way of life, choice of jobs, access to the lagoon, manner of "dwelling in" the environment, politics, etc. The island is surrounded by a coral barrier reef (see geomorphology in Andréfouët et al., 2009) of 1,600 km in length, the world's second-largest barrier reef system, just behind Australia's Great Barrier Reef (Cuif et al., 2014). Its outstanding biodiversity (8,783 species inventoried, Payri and Richer de Forges, 2006) and its natural ecological habitats that are important for biodiversity conservation (coral reefs, mangroves, seagrass meadows, rocky coastlines, silty bay bottoms) generated growing interest from the 1980s onwards, culminating in 2008 when 15,000 km^2 of reef zones were given UNESCO World Heritage status, thus conferring international recognition of the exceptional value of these coral reefs.

The program involved elementary schools located in urban, coastal and rural areas. Five schools were selected (**Figure 1**): Paul Boyer (Nouméa, socially advantaged urban neighborhood), Isidore Noell (Nouméa, less advantaged urban neighborhood), Thio (close to a marine protected area), Banian (Yaté, within a large fishing community) and Coula Gondé (Houaïlou municipality, rural environment, at about 30 km from the sea, without regular public transport). This selection enabled coverage of populations that varied geographically, environmentally, economically and socially, thus potentially shaping the diversity of children's representations, knowledge and uses of coral reefs and their threats. The same criteria were used for all schools participating in the program, integrating recommendations from the educational authorities involved. The sampling is based on voluntary participation in the program by the heads of the selected schools, and more specifically teachers interested in the MARECO toolbox. A scientific protocol using this toolbox was implemented in each of these schools, in order to provide the same foundation of messages about the coral reefs conveyed by the educational games to all children. 88 children (55% male, 45% female) took part in the research program. They were distributed between classes of 1st Grade (15%) and 2nd Grade (85%), and their average age was 7.2 years (**Table 1**). Children of around 7 years old where targeted because at this age playing is a central mechanism in learning and they are old enough to be able to draw and explain their drawings.

The Teaching Toolbox Mareco

The teaching toolbox MARECO[1] is bilingual (French-English), a vernacular language having been added to the picture book. The toolbox comprises three educational games focusing on the importance and vulnerability of coral reef ecosystems and their management. The games in MARECO aim to convey key knowledge and concepts.

1- The picture book *The Colors of the Reef* focuses on the diversity and vulnerability of the coral ecosystem in the face of natural and human-induced disturbances;
2- The card game *Coral Reef Happy Families* focuses on biodiversity and interactions between the coral reef's species;
3- The board game *See You At The Reef* focuses on the place of humans within the coral ecosystem, and the necessity of cooperation between ocean users, stakeholders and the population to ensure the sustainability of the interactions between coral reefs and humans.

A teacher's handbook presents these games, together with suggestions for teaching activities.

The main messages of the MARECO educational tool kit are (**Table 2**).

1- The coral is a living animal, the polyp, represented by a tiny soft animal called Poly, who leads the players through all three games;
2- The reef is a place of high biodiversity (card game);
3- The reef is an ecosystem; species have important interactions with each other and the environment, including humans, and cannot exist without all the other species (card game, picture book);

[1]see http://umr-entropie.ird.nc/index.php/portfolio/projet-reso-ecorail and link with a film, "The Coral Reefs in Our Hands." Trade protection and an operating license by a games publisher is currently under process for the MARECO toolbox.

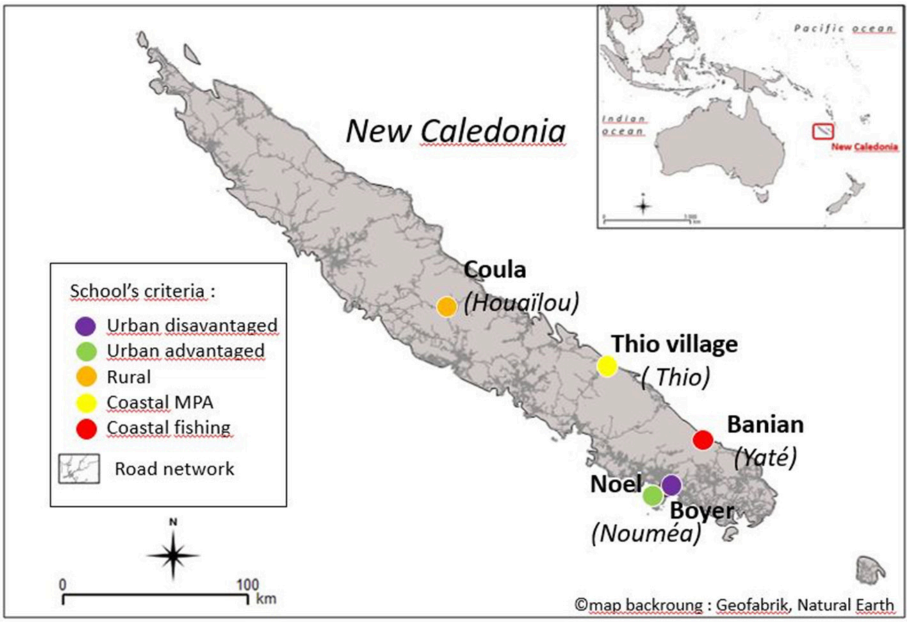


FIGURE 1 | Map of New Caledonia and location of the schools.

TABLE 1 | Distribution of children in classes by municipality and school according to the school level (G1,1st Grade; G2, 2nd Grade), age and gender (F, female; M, male).

Municipalities (schools)	G1 (%)	G2 (%)	F (%)	M (%)	Age	∑
Nouméa (Boyer)		100	36	64	7.3	22
Nouméa (Noell)		100	61	39	7.6	23
Thio	56	44	56	44	6.8	16
Yaté (Banian)		100	44	56	7.4	16
Houailou (Coula)	36	64	18	82	6.7	11
TOTAL	15	85	45	55	7.2	88

Boyer, socially advantaged urban neighborhood; Noell, less advantaged urban neighborhood; Thio, coastal area close to a marine reserve; Banian, coastal area within a large fishing community; Coula, rural environment.

4- Humans are part of the system; they interact with other species, and break, repair, protect the coral reef ecosystem (picture book, board game).

Data Collection

The data on children's representation of coral ecosystems were collected via a three-phase protocol implemented in each of the schools (**Table 2**):

- First phase. The children were asked to make two drawings following these instructions: first "Draw me the sea" and then "Draw me the coral reef," the children were given 20 min for each drawing, one after another. When the drawings were finished, each child was interviewed in order to gather information, name the elements that were drawn, and also acquire explanations about the possible direct and indirect experiences of children with the coral reef.

TABLE 2 | Different steps of games during the protocol before the teaching toolbox MARECO is left with the classes; and the messages associated with the games (1: The coral is alive; 2: The reef is a place of high biodiversity; 3: The reef is a whole; species interact with each other and the environment, including humans; 4: Humans are part of the system; they interact with others species, and enjoy, break, repair and protect the coral reef ecosystem that provide many services.

	Step 1	Step 2	Step 3
Card game (1, 2, 3)	Discovering the reef's inhabitants	Interaction between species (food chain)	Interactions between reef inhabitants and humans (food from the reef)
Picture book (1, 3, 4)	Discovering the coral ecosystem	The colors of a healthy reef	Pollution on the reef
Board game (4)	Destroying the reef without users' collaboration	The impact of collaboration on reef users	Roleplays and the importance of co-management

- Second phase. Nine activities with the three games were conducted by scientists and calibrated: for a duration of 30 min each, each game was used three times over three successive days with a view to giving the children the same messages and to familiarizing them with the games (see details in **Table 2**).

The teaching toolbox MARECO was then given to the teacher for a duration of 2 months. The teacher carried on with the toolbox activities in accordance with the class's teaching program in order not to interfere with the program.

- Third phase. The children made a last drawing of the coral reef 2 months after using the toolbox with the scientists. When the drawings were finished, the children were interviewed to gather information about the elements of the drawing.

Before each drawing session, the same boxes of colored pencils, containing 12 colors, were distributed to the children, together with half sheets of white drawing-paper. A total of 248 drawings were collected.

This study was carried out as part of the school curriculum in accordance with the recommendations of the National Education Directorate of New Caledonia that approved it (agreement n° CS16-3700-132, 20 April 2016).

Data Analysis

The items recorded in the drawings of each child were transformed into qualitative and quantitative data transcribed in a matrix with 16 quantitative variables belonging to three categories, seven for living natural items, four for seascape (non-living) items and five for human-related items (**Table 3**). The textual information, such as the list of the types of animal or plant items which the child had named during the census of items (belonging to the marine or terrestrial ecosystems), was saved in a database, together with the scans of the drawings needed for the interpretations of the results.

Data analysis was conducted in three stages in order to analyze the differences in coral reef representations before and after the awareness campaign using MARECO.

An initial stage describing the children's representations of marine ecosystems (sea or coral reef) consists in an exploratory multivariate analysis aiming at describing the structure of the data (individuals, i.e., the drawings, and variables) over the whole of the dataset (Sea-Reef1-Reef2). This analysis will notably enable the positioning of the drawings of the reef (before and after MARECO) compared to those of the sea, in order to analyze the children's relationships with nature as seen through their drawings. A Principal Component Analysis (PCA) is performed on the matrix describing the 248 drawings according to the three themes (sea and reef) and school (Thio, Noell, Boyer, Coula, Banian), from the log-transformed data of the 16 variables (**Table 3**), so as to make it conform more closely to normal distributions and obtain a better synthesis of the data on the factorial axes. With the technique of supplementary variables, the gravity centers of individuals (drawings) clustered in relation to explanatory variables (theme of the drawing—Sea-Reef1-Reef2—or school) are indicated in the first factorial plane with an ellipse bounding 95% of points or based on the calculation of a confidence interval of 95% around the gravity centers. Finally in order to take into account the non-independence of the samples and longitudinal data (the same children being involved in the program's framework for the three drawings), each child is compared with himself/herself to analyze the evolution of the

TABLE 3 | List of drawing descriptors (categories, variables) used to assess the representations of sea or coral reef.

Categories	Variables (codes)	Description
Living natural items	Number of flora types *(Nb_flora_type)*	Count of upper taxonomic levels including terrestrial and marine (tree, seagrass, seaweed …)
	Number of marine or terrestrial flora organisms *(Nb_flora_ind)*	Count of individuals
	Number of terrestrial fauna organisms *(Nb_terrestrial_ind)*	Count of individuals (including aerial organisms such as birds)
	Number of types of marine organisms *(Nb_fauna_type)*	Count of upper taxonomic levels (fish, mollusc, turtle, mammal, etc.…)
	Number of marine phenotypes *(Nb_ fauna_phenotype)*	Count of lower taxonomic levels, based on the change in form or color used to draw the marine organisms
	Number of marine organisms *(Nb_fauna_ind)*	Count of individuals
	Presence/absence of biological life-cycles *(Bio_cycle)*	Binary variable to pinpoint the presence or not of the biological life-cycle processes (predation, reproduction, migration, …)
Seascape items	Number of environmental items *(Nb_environment)*	Count of non-living environmental items (sea, land, sand, cloud, sun, …)
	Presence/absence of continental items *(Continent)*	Binary variable to pinpoint the presence or not of the continent (beach, island, mainland, …)
	Presence/absence of infrastructural items *(Infrastructure)*	Binary variable to pinpoint the presence or not of infrastructures built by humans (bridge, house, wharf, road, …)
	Number of colors *(Nb_color)*	Count of colors used in the drawing from a range of 8 colors (yellow, orange, red, pink/purple, blue, green, brown and black)
Anthropogenic items	Number of humans *(Nb_human)*	Count of men, women or children
	Number of marine users *(Nb_user)*	Count of users of the sea (sailor, fisher, swimmer, diver, …)
	Number of type of marine activities *(Nb_activity)*	Count of types of human activities linked with the sea (boating, on the beach, management, …)
	Number of technology items *(Nb_technology)*	Count of technology items built by humans, linked or not with the sea (motorboat, fishing gear, anchor, beach umbrella, beach chair, bottle, flag, …)
	Number of types of boats *(Nb_boat_type)*	Count of different boat types (sailboat, motorboat, fishing boat, transport vessel, …)

*A short description is given for each variable. A code (in italics) is associated with each variable (used in **Table 4** and for statistical analyses).*

drawings between Sea and Reef1, and between Reef1 and Reef2, via a t-test for paired data. The relations between qualitative variables (e.g., age vs. school) are tested by a Pearson's Chi-squared test.

A second stage aims to test the pertinence of the "number of colors" as a relevant indicator of representations through drawings. The hypothesis that the number of colors is an indicator of the other variables describing the sea or coral reef drawings is tested by statistical analysis. Because the samples Sea, Reef1 and Reef2 are non-independent as seen above, the means of the indicator "number of colors" in the drawings are compared between Sea and Reef1 and Reef1 and Reef2 via a t-test based on paired data. As the variable "marine phenotype" is built on the basis of the count of the individuals represented by a different shape or color, and is thus a direct function of the number of colors, only two variables of marine fauna biodiversity are used to avoid too much collinearity in the model: the number of marine types and the number of individuals. Data normality is tested by a Kolmogorov-Smirnov test in order to verify the conditions required for the statistical tests used in the following analyzes: multiple regressions to explain the number of colors by all other quantitative variables and multifactorial variance analyses to test the effect of schools or the drawings' themes on the number of colors, followed by a Tukey-test of multiple comparison of means. Owing to the fact that the samples are not independent and quantitative variables not normal, the validation phase of the model's outputs is an essential stage in the statistical procedure (see discussion). To this end, an analysis is conducted of the normality of residuals, their homoscedasticity (homogeneity of variance of residuals according to the estimated variable) and their independence (absence of apparent correlation). Moreover, the residuals are checked against explanatory factors of the variable to be explained ("number of colors"), i.e., the theme of the drawings, school, class level, and gender.

Finally, the third stage of data analysis takes into account the impact of MARECO more directly via analysis of the indicator variable "number of colors" on a reduced dataset (Reef1 and Reef2, 170 drawings) to better understand the factors explaining the change or shift in representation in the coral reef drawings after the use of MARECO. This analysis is conducted via a multifactorial variance analysis in which the explanatory factors are: school criteria (socially-advantaged urban neighborhood, disadvantaged urban neighborhood, close to a marine protected area, fishing environment or rural environment), the drawing's theme (Reef1, Reef2), class level (two grades: first year of elementary school, second year of elementary school) and gender (male and female).

RESULTS

Analysis of the Evolution of the Representation of Marine Ecosystems

The PCA conducted on the 248 drawings, including the three themes (Sea—Reef1—Reef2), the five schools (**Figure 2**) and described by the 16 quantitative variables (**Table 3**), explains 56.8% of the variability of the observations on the first three factorial axes (24.9, 17, and 14.9%; axes 1, 2, and 3, respectively).

The first factorial plane (axis 1 vs. axis 2) shows three patterns. The first axis separates marine fauna biodiversity from human activities (and, to a lesser degree, presence-absence of

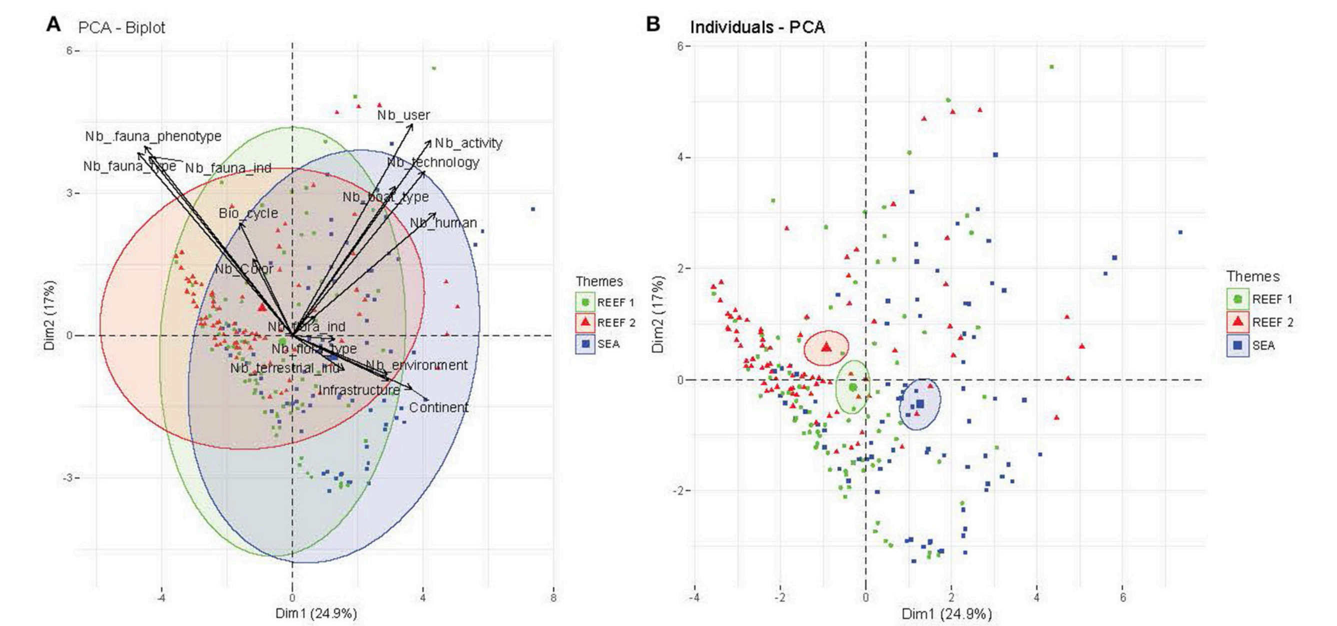


FIGURE 2 | Analysis of 248 drawings and 16 quantitative variables with Principal Component Analysis (PCA) (see **Table 3** for the listing of the variables). **(A)** Individuals (drawings) vs. variables that explain the two first axes; the ellipses delimit 95% of the individuals of each drawing's theme: Sea (blue), Reef1 (green, before MARECO), and Reef2 (red, after MARECO). **(B)** Individuals (drawings) and barycenter of the clouds of points with their confidence interval (confidence ellipse).

infrastructure, continent and non-living environment linked to the negative part of axis 2), which are both linked with the positive part of the second axis (**Figure 2A**). The variable "colors" is related to "marine fauna" but also with "flora," "terrestrial fauna," or "environment" on the third axis (not presented here). The cloud of individuals relating to the group Reef2 shows greater homogeneity of the samples of drawings (the ellipse containing 95% of the points is circular), whilst Sea and Reef1 demonstrate great variability in the drawings, with three trends: (i) drawings that are poor in information, whether pertaining to living organisms or human activities (negative part of axis 2); (ii) drawings rich in biodiversity (negative part of axis 1 and positive part of axis 2); (iii) drawings with representations of humans (positive part of axes 1 and 2). The gravity centers of the five schools reveals that they are slightly separated on the first factorial plane, but with an overlapping of the point clouds (**Figure 3A**).

The gravity centers of the groups (theme of the drawing or school) are positioned on the factorial plane with confidence ellipses corresponding to the confidence interval at 95% of the mean of the coordinates of each drawing of the group (**Figures 2B**, **3B**). Analysis of the confidence ellipse around the gravity centers shows in **Figure 2B** that axis 1 differentiates the theme "Sea" from the theme "Reef" (Reef1-Reef2), whilst axis 2 differentiates the drawings made before and after the use of MARECO (Sea-Reef1 vs. Reef2). In **Figure 3B**, axes 1 and 2 differentiates Coula and Boyer from the other schools, owing to the elements in the drawings relating to, respectively, the most frequently represented humans or marine biodiversity. A gradient is observed between Thio < Noell < Banian < Boyer on axis 2, moving from the negative part to the positive part of the axis, and therefore from the least rich to the richest regarding marine biodiversity and/or human-related items.

The comparison of paired data between Sea-Reef1 and Reef1-Reef2 of the various quantitative variables shows highly significant differences ($p < 0.001$) between (i) Sea and Reef1 for seven variables (Number of flora types, Number of terrestrial fauna organisms, Number of types of marine organisms, Number of marine phenotypes, Number of marine organisms, Number of environmental items, and Presence/absence of continental items), and (ii) Reef1 and Reef2 for five variables (Number of colors, Number of flora types, Number of types of marine organisms, Number of marine phenotypes, Number of marine organisms) (**Table 4**). An average of 4.6 marine phenotypes are represented per drawing (all types of drawing), with a distinct increase in the number of phenotypes in the drawings of the Sea, Reef1 and Reef2 (2.3, 4, and 7.6 phenotypes, respectively). This trend is also observed for the number of colors with the majority of the children used 5, 6, or 7 colors with a mean of 5.7 colors from the proposed color palette (8 from a box of 12 colored pencils) (**Figure 4**).

Although the initial variables are not normal (raw or log-transformed data), the deviations Sea-Reef1 ($\boldsymbol{\Delta}_{SR1(i)}$) and Reef1-Reef2 ($\boldsymbol{\Delta}_{R1R2(i)}$) are normal (Kolmogorov-Smirnov test, $p > 0.05$) and independent, thus enabling testing of the "school" effect and the link between the "color" variable and the other variables, whilst respecting conditions for applying parametric statistical tests.

Analysis of the Variable "Number of Colors"

The multiple regression model between the number of colors and quantitative variables established from the raw data and the three samples of drawings (Sea, Reef1, Reef2) accounts for 27.6% of the variability of colors (highly significant model, $p < 0.001$). The residuals are normal (Kolmogorov's $D = 0.146$, $p = 0.09$), with values showing a slight deviation from zero and from the estimated values at the extremes of the color palette (**Figure 5**). The residuals, checked against the variable "child's age," show that the number of colors is slightly underestimated (negative residuals) for the oldest children (9 years of age), who therefore use the most colors in their drawings. The model's

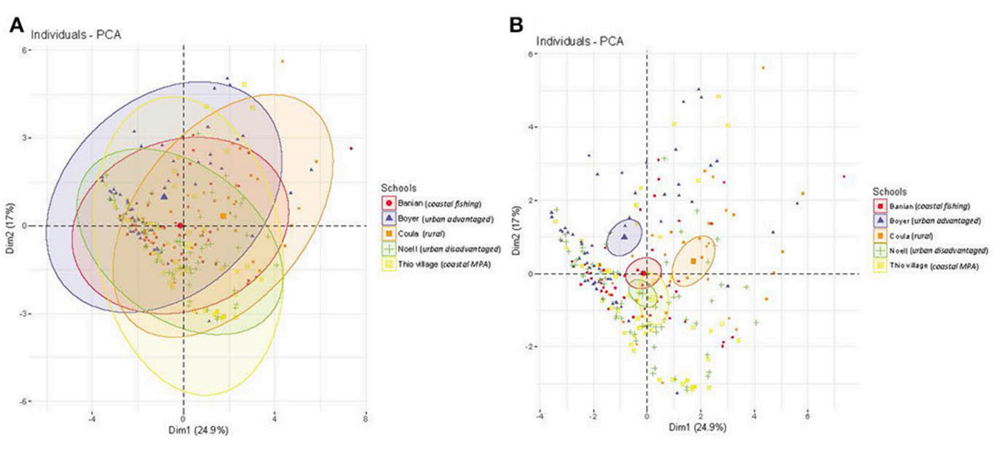


FIGURE 3 | Analysis of the 248 drawings and 16 quantitative variables with Principal Component Analysis (PCA) (see **Table 3** for the listing of the variables). **(A)** Individuals (drawings) with the ellipses delimiting 95% of the individuals of each drawing's school: Banian (coastal area within a large fishing community, in red), Boyer (socially advantaged urban neighborhood, in purple), Coula (rural environment, in orange), Noell (less advantaged urban neighborhood, in green) and Thio village (coastal area close to a marine reserve, in yellow). **(B)** Individuals (drawings) and barycenter of the clouds of points with their confidence interval (confidence ellipse).

TABLE 4 | Deviation for each variable between Sea/Reef1 and Reef1/Reef2: Mean of deviation and *t*-test of paired data with significance (****p* < 0.001, ***p* < 0.01, **p* < 0.05).

Variables (i)	$\Delta_{SR1(i)}$ = Sea-Reef1	$\Delta_{R1R2(i)}$ = Reef1-Reef2	Mean ± sd SEA	Mean ± sd Reef 1	Mean ± sd Reef 2
Nb_colour	0.43*	−1.43***	5.5 ± 1.30	5.1 ± 1.56	6.6 ± 1.26
Nb_flora_type	0.54***	−0.47***	1.0 ± 0.88	0.46 ± 0.61	0.96 ± 0.73
Nb_flora_ind	1.15	−3.12**	2.8 ± 6.02	1.7 ± 5.14	4.6 ± 8.71
Nb_terrestrial_ind	2.82***	−1.44	6 ± 6.35	3.2 ± 5.25	4.8 ± 6.31
Nb_fauna_type	−0.92***	−1.99***	1.3 ± 1.51	2.2 ± 1.65	4.3 ± 2.49
Nb_ fauna_phenotype	−1.73***	−3.67***	2.3 ± 2.96	4.0 ± 2.89	7.6 ± 4.11
Nb_fauna_ind	−5.34***	−3.82***	5.0 ± 5.86	10.0 ± 9.90	14.0 ± 9.28
Nb_human	0.66*	0.46	1.9 ± 2.25	1.2 ± 2.72	0.82 ± 1.93
Nb_user	0.07	0.21	0.57 ± 1.16	0.49 ± 1.93	0.33 ± 0.70
Nb_environment	0.96***	−0.14	3.8 ± 1.17	2.8 ± 1.23	3.0 ± 1.39
Nb_activity	0.20*	0.03	0.51 ± 0.75	0.3 ± 0.56	0.3 ± 0.64
Nb_technology	0.33	0.22	0.88 ± 1.61	0.54 ± 1.21	0.35 ± 0.75
Nb_boat_type	0.20**	−0.05	0.36 ± 0.63	0.16 ± 0.37	0.23 ± 0.53
Bio_cycle	−0.11*	−0.04	0.072 ± 0.27	0.18 ± 0.39	0.21 ± 0.41
Infrastructure	0.15**	0.03	0.34 ± 0.48	0.19 ± 0.40	0.17 ± 0.40
Continent	0.23***	−0.05	0.65 ± 0.47	0.42 ± 0.50	0.47 ± 0.50

*See **Table 3** for variable descriptions. If $\Delta_{MR1(i)}$ > 0, then Sea > Reef1 or Reef1 > Reef2.If $\Delta_{RR2(i)}$ < 0, then Reef1 > Sea or Reef2 > Reef1. Means and standard deviation are given for each variable by theme of drawings.*

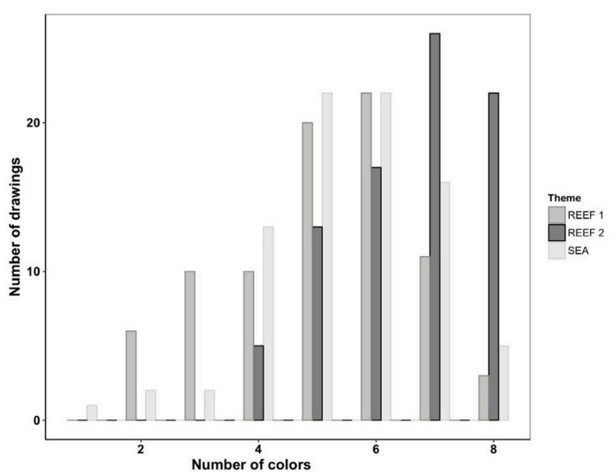


FIGURE 4 | Evolution in the number of colors used according to the themes (Sea, Reef1 and Reef2). Axes: number of colors vs. number of drawings.

estimated parameters together with their explanatory power are indicated in **Figure 5**. The number of colors is explained by the numbers of types of marine fauna ($p < 0.001$) and flora ($p < 0.01$), the number of marine organisms ($p < 0.01$), the number of elements of non-living environment ($p < 0.01$) and, at the limit of significance threshold ($0.05 < p < 0.1$), the number of terrestrial organisms and the number of users of the sea. Residual structure shows no significant relationships with the schools, themes, gender or class level: no variable accounts for the slight heteroscedasticity and particular structure of the residuals (point alignment). Although the model is significant, there remains approximately 73% of the variability of number of colors in the residuals: this residual variability is due to the heterogeneity between children but also between the schools and the themes of the drawings. Because of the non-respect of independence of observations, four other multiple models are established, by separating the samples (one model for each drawing theme) and by working on the deviations between Sea-Reef1 and Reef1-Reef2. In all four cases, the residuals of the models are normal, always featuring the same phenomenon: a deviation at the extremes of the number of colors, aligned in decreasing order.

When the analysis is conducted according to schools, the median values and the quartiles per school show a significant difference in the use of colors between the schools (**Figure 6**). Sea and Reef1 do not show a marked difference, but the drawings often present fewer colors in Reef1, with the exception of Boyer school, and the mean of differences based on paired data is at the limit of the significance threshold at 5% ($\Delta = 0.43$; $p = 0.045$, **Table 4**). For Reef2, after the use of MARECO, Boyer, Coula, Banian, and Thio schools present drawings with more colors than for Reef1. The difference on paired data (mean of deviation) is highly significant ($\Delta = -1.43$, $p < 0.001$, **Table 4**).

The number of colors (raw, log-transformed or square root data) do not correspond to a normal distribution. Despite the non-independence of the samples and the non-normality of the variable "color," and considering the robustness of the variance analysis model, the effect of the factors "theme" and "school" is tested, followed by a multiple comparison test. The validation of the model (results not pictured) shows that the residuals on raw variables are normal (Kolmogorov-Smirnov test and a right-skewed Normal Q-Q plot on standardized residuals). The model accounts for 27.2% of total variability (inter-group variability/total variability) with the "theme" factor emerging as highly significant ($p < 0.001$), the "school" factor as significant

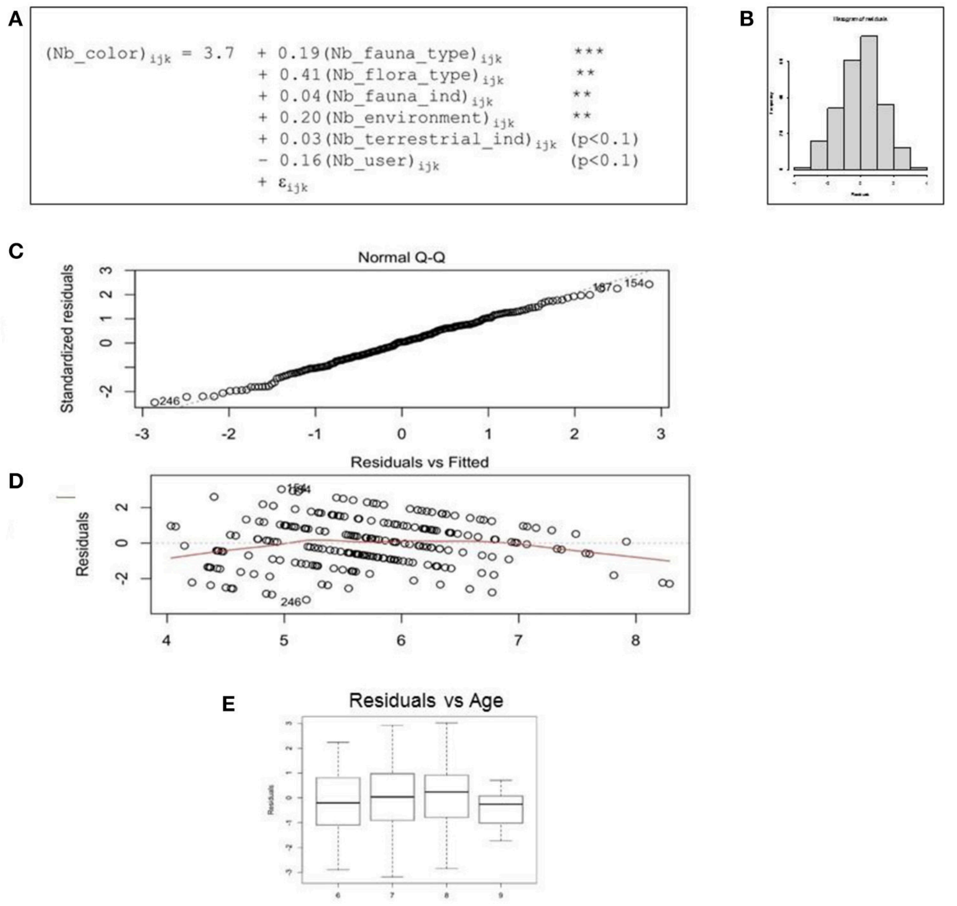


FIGURE 5 | Validation of the multiple regression model established between the number of colors and 14 quantitative variables describing the drawings (**Table 3** without number of marine phenotype). **(A)** regression model used with the most significant variables (***$p < 0.001$, **$p < 0.01$, and $0.05 < p < 0.1$), **(B)** histogram of residuals, **(C)** quantile-quantile plot of the standardized residuals, **(D)** standardized residuals vs. fitted values, **(E)** box plot of standardized residuals vs. children's age.

($p < 0.05$), and the interaction between "theme" and "school" as highly significant ($p < 0.001$). The residual plot according to estimated values shows no particular structure, and the residual mean is equal to zero with homogeneous variance. The model is therefore valid, despite the non-respect of application conditions. Considering the relationship between "school" and "class," it is important to interpret the results while taking into account the fact that Coula and Thio each have a mixed 1st/2nd grade class, compared to the three other schools whose classes are only 2nd grade (**Table 1**).

In order to confirm the above results, a new variance analysis is established from the data deviations (**Table 4**) according to the "school," "age," and "gender" factors, in order to take the non-independence of the samples into account (results not pictured). The results confirm the fact that the "school" factor is very significant ($p < 0.01$) between Sea and Reef1, and significant ($p < 0.05$) between Reef1 and Reef2. The significant effect of the "school" factor is due to the difference between Boyer and Coula (Tukey's test, $p < 0.05$), and to a lesser degree between Banian and Coula (Tukey's test, $p = 0.06$). Nonetheless, the indicator variable ("number of colors") shows larger differences between the themes Reef1 and Reef2 ($p < 0.001$) than between Sea and Reef1 ($p < 0.05$) (paired *t*-test, **Table 4**). Indeed, the deviation in the number of colors is positive between Reef1 and Reef2 ($\Delta_{SR(i)} = 0.43$), and negative between Sea and Reef1 ($\Delta_{RR2(i)} = -1.43$). These results show that (i) the drawings of Reef1 (mean $= 5.1 \pm 1.56$) are less colorful than those of Sea (mean $= 5.5 \pm 1.30$), and (ii) the drawings of Reef2 (mean $= 6.6 \pm 1.23$) are more colorful than those of Reef1. Nonetheless, this effect needs to be moderated according to the schools.

It remains that the variance analysis model brings to light the fact that it is *via* the interaction between the themes and the schools that the differences can be understood (**Figure 6** and result of multiple regression). The "school" effect is therefore more marked for the drawings between Sea and Reef1 or Reef2 than between Reef1 and Reef2. This completes the result found by the PCA, i.e., that the content of the drawings is more homogeneous after the use of MARECO and that the children in certain schools demonstrate knowledge of the coral reef in the first drawing.

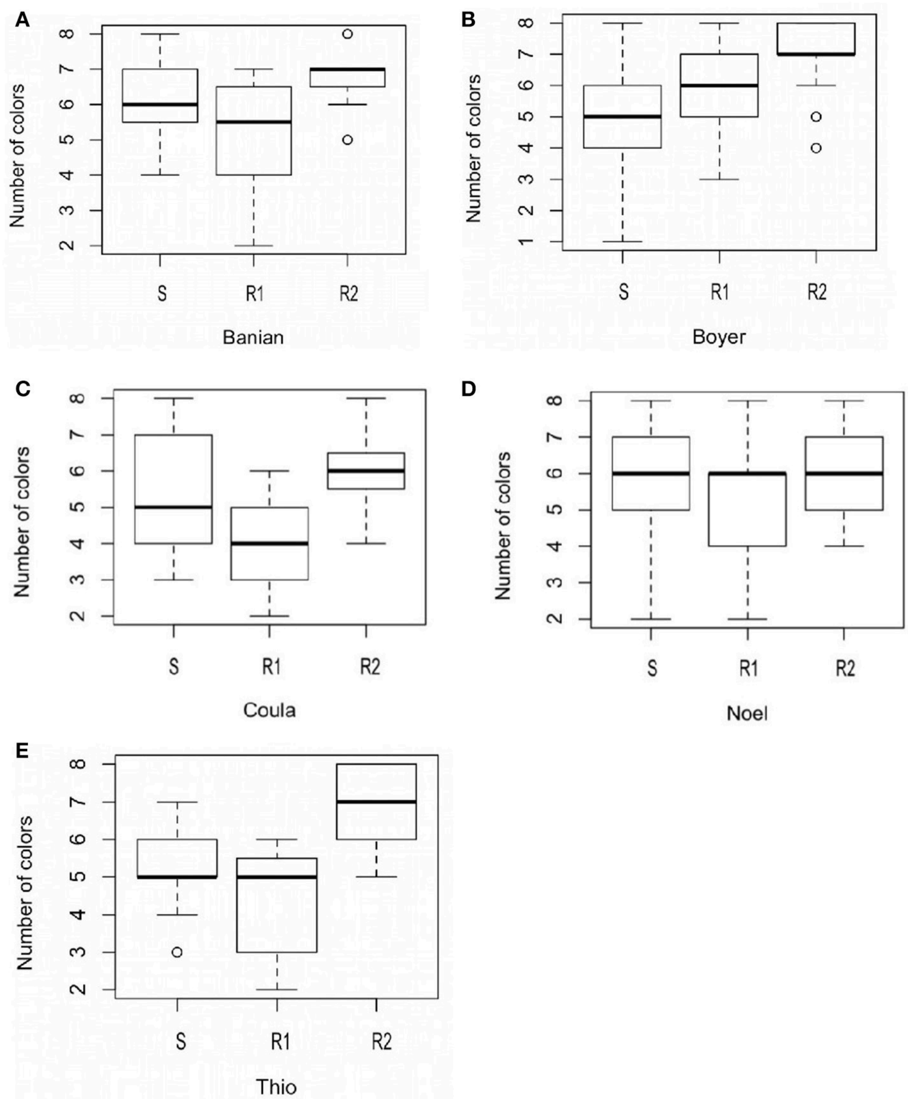


FIGURE 6 | Quantile's box plot of the number of colors used in the drawings between Sea, Reef1 and Reef2 per school. **(A)** Banian (coastal area within a large fishing community), **(B)** Boyer (socially advantaged urban neighborhood), **(C)** Coula (rural environment), **(D)** Noell (I less advantaged urban neighborhood), **(E)** Thio (coastal area close to a marine reserve).

MARECO Effect

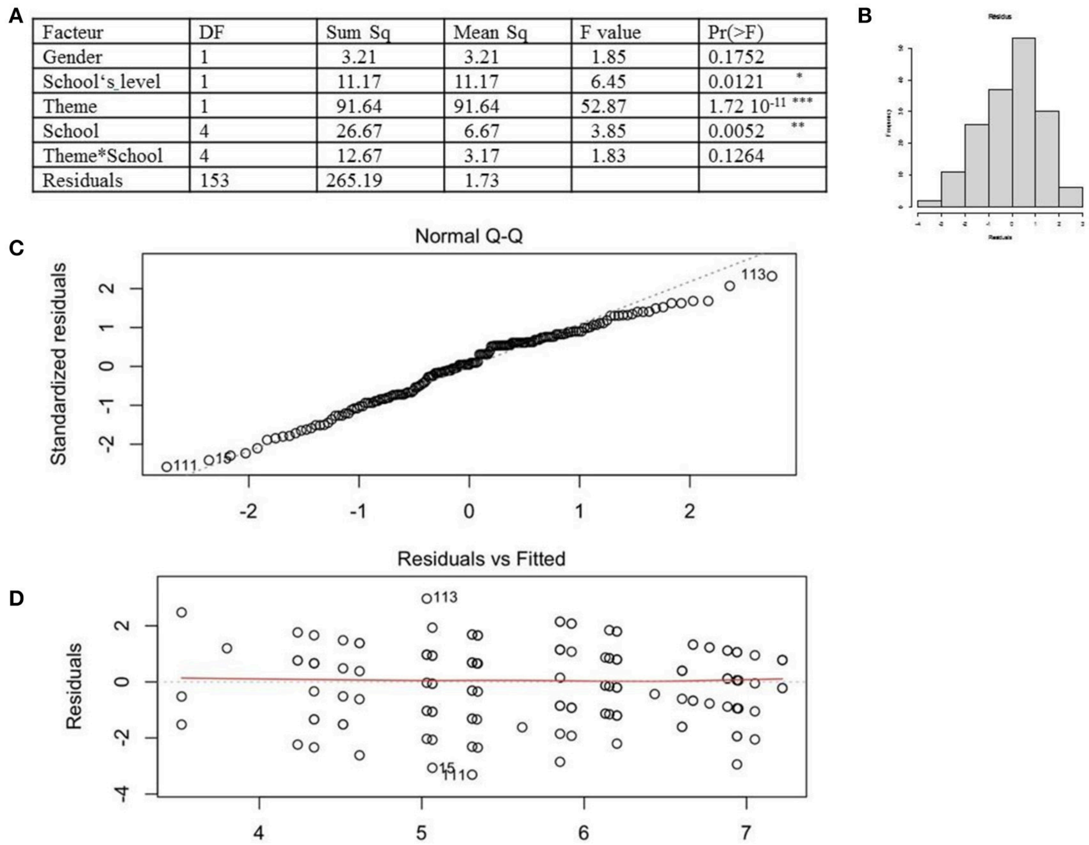
The model from the multifactorial variance analysis to test the MARECO effect is totally validated: residual normality, variance homoscedasticity and absence of correlation structure in the residuals according to the variable number of colors to be estimated (**Figure 7**). With respect to the total variability, the model explains 35.4% of the variability of the number of colors. The class level, and therefore the children's age, gives rise to a significant effect ($p < 0.05$), with the theme of the drawing being highly significant ($p < 0.001$) and the school very significant ($p < 0.01$).

The results of the three phases of the analysis procedure enabled the various working hypotheses to be tested:

Hypothesis 1 verified. The groups of children in the different schools (with contrasting natural and socio-cultural environments) have specific representations of the marine ecosystems.

Hypothesis 2 verified. The numbers of colors used by the child for the drawings can be used as an indicator that the child has developed a holistic perception of coastal sea or coral reef.

Hypothesis 3. The impact of MARECO is assessed on the basis that the child has developed a holistic perception of the coral reef combining (a) biodiversity, (b) human activities, and (c) environment. Regarding the three points set out in this hypothesis, Point (a) and to a lesser extent Point (c) are verified. Conversely, Point (b) is rejected for the majority of children.



Facteur	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Gender	1	3.21	3.21	1.85	0.1752
School's level	1	11.17	11.17	6.45	0.0121 *
Theme	1	91.64	91.64	52.87	1.72 10^{-11} ***
School	4	26.67	6.67	3.85	0.0052 **
Theme*School	4	12.67	3.17	1.83	0.1264
Residuals	153	265.19	1.73		

FIGURE 7 | Validation of multifactorial analysis of variance on the number of colors according to the explanatory factors of the representations: gender, class level, theme and school. **(A)** Table of variance, **(B)** histogram of residuals, **(C)** quantile-quantile plot of the standardized residuals, **(D)** standardized residuals vs. fitted values.

The discussion will address these hypotheses, together with the research methodology and MARECO's contributions as an educational tool for increasing awareness of coral environments.

DISCUSSION

Research Methodology

An interdisciplinary approach between social, ecological and biological sciences is now encouraged and practiced, but communication beyond the research methodologies is rare and leads to poor understanding of the interactions registered within the socio-ecological system (Chaboud et al., 2011; Stoica, 2012; Fabinyi et al., 2014). In this study, interdisciplinary skills (anthropology, ethnoecology, marine biology, biostatistics) were involved in order to develop the research methodology and improve data collection and interpretation. "Drawing to see" (Causey, 2016) and coding qualitative data to quantitative data for data analysis of the drawings are the heart of this interdisciplinary research program. Taking into consideration all the cases studied and the overall research process, methodological limits are referred to: (i) a continuous evolution of the research methodology that might be considered simultaneously a strength and a weakness; and (ii) the practice of interdisciplinarity "in the field" but also during "brainstorming" activities where the different steps of the research were discussed, modified and approved. Practical examples will illustrate each of the two points. For the first point, one of the major difficulties during the research was the "drawing task" and the instructions that were given in the classroom in order to make the "concept" of *coral reef* understandable to children. While the first drawing of the "sea" posed no problem, the second one relating to the "coral reef" provoked different reactions in the children. During the research process, the "drawing task" was constantly improved by asking one of the children who knew what a coral reef is to explain briefly what it represents. By choosing this strategy, the research team tried not to interfere or to orient children in their drawing representation. The second refers to the practice of interdisciplinarity and the "divergent points" of view related to each discipline. As an example, the exchanges and discussions developed during the selection and definition of criteria to be used to summarize and "read" the items depicted in the drawings were different and had different "understandings" for the disciplines involved in the project. Words such as *life cycle*, *protocol, replicate, homogeneity* may have different meanings in biology and anthropology or not usual for one discipline. A long and lively discussion was also had in reference to the term "ethnospecies," which is usually used in relation to folk taxonomy and to how local people name the identified species they perceive, but which may not correspond to the biological one (Linnaean classification, for example) (Ellen, 1993). This term has been finally named "phenotypes" in this paper. These methodological limits drove us on the one hand to be aware of the difficulties of exchanging between disciplines, but on the other hand pushed us to revisit and reconsider our viewpoints and improve our strategy through a double process of critical reflection and understanding of the "problematic" issues that were encountered during the research process.

Once the data acquisition method has been validated and the data acquired, coding is an essential point in the analysis procedure (Thomas, 2006) as it orients the results obtained, but may also be a source of bias owing to errors made by the coders. The solidity of this point was reinforced by a double coding carried out by two people simultaneously. Finally a particular emphasis was placed on the validation of the statistical procedure which is based on the combining of exploratory and confirmatory approaches. Apart from PCA, a descriptive multivariate analysis enabling a global analysis of the dataset and the identification of the main sources of variability, the validating of the statistical models used were made respecting the recommended steps for data exploration and general linear model (Zuur, 2012). Exploring the models' residuals (e.g., **Figures 5**, **7**) enables the statistical model to be validated even if the application conditions are not completely verified: the main issue we faced was the non-independence of the observations, owing to the fact that the same children were involved in all three data samples (drawings for Sea, Reef1, and Reef2). This problem was countered in two ways: (i) cross-validation of the results obtained by conducting various analyses, notably paired data analysis, and (ii) validation of the model via analysis of the residual variability unexplained by the model. For instance, residual analysis of the regression model established on the number of colors vs. all the other quantitative variables enables the model to be validated whilst positing one hypothesis to explain why there are residuals slightly different from zero at the extremes of the palette of eight colors (**Figure 5D**). If a child uses more colors that the model predicts in view of the elements drawn, this might be explained by the fact that the child like colors, and therefore by its artistic side (e.g., rainbow). The tendency to see negative residues for older children (but not significant, **Figure 5E**) can also be explained by the degree of development of children and their ability to draw compared to younger ones.

Whatever the case may be, opting for the number of colors as an indicator for studying the MARECO effect is ultimately is finally a subtle choice, for it touches on behavioral aspects regarding the act of drawing that are largely beyond the scope of this paper, with notably a potential relationship with the child's degree of development, and thus their age but also with aspects related to the creativity of the child (Goodenough, 1926). As the research procedure is based on analyzing and comparing the groups, we restricted ourselves to the analysis of intra- and inter-group variability in order to tackle the issue of social representations without engaging in considerations of individual representation (Doise et al., 1992; Abric, 2003).

Children's Representations of Nature and Ecological Knowledge

Since children will be the adults of the future, it is important to understand their representations of nature in a changing world (Eriksen, 2016). These representations and knowledge are based on their interactions with other humans about the living environment, education received and children's direct experience with this aspect of nature (Battesti, 2007; Dounias, 2007; Calandra, 2013; Gallois et al., 2017). These interactions with nature might be indirect (viewing nature through a window at work or at home), incidental (spending time outside at work), or intentional (time spent in recreational activities). The groups of children who took part in this study were not chosen randomly but belong to a same classroom in different areas that are socioeconomically and ecologically contrasted, and vary in age. Despite these common criteria, the children each have their own lives, identities, beliefs and experiences, and thus their perception of nature is likely to appear in their drawings (Carrière et al., 2017). Nevertheless, social interactions between the children, their parents and teachers will mutually influence the representations of coral reef ecosystems in each child's group and thus similarly influence their encompassing perception of nature. It is therefore more likely that children, who may be considered as a social group, from the same class in a specific school, share the main representations of their environment, as a social group of adults (Ellen, 2006). This is confirmed by our first hypothesis, which establishes that the groups of children in the different schools have specific representations of the marine ecosystems, both of the sea and the coral reef, while children in the different schools show disparities in their drawings. Our results highlight differences between schools and differentiated three main patterns before the awareness campaign (**Figure 8**): (i) schoolchildren in less-advantaged urban environments and in coastal areas close to a marine reserve, but with a natural environment impacted by human-related activities, have drawings that are poorer in biodiversity or human activities; (ii) schoolchildren in socially advantaged urban environments or fishing environments in coastal areas have coral reef drawings that are richer in biodiversity compared to other schools, and (iii) schoolchildren in rural environments at a distance from the sea have drawings mostly characterized by the presence of humans, but with a low representation of marine biodiversity.

Greater marine biodiversity in drawings before the MARECO protocol by schoolchildren in the socially-advantaged urban environment can be explained by the richness of the environment offered to them within the educational system (Kopnina, 2012). The majority of urban people have weaker or non-existent traditional ecological knowledge compared to rural or fishing societies (Hurrell and Pochettino, 2014). This ecological knowledge acquired through direct and ancient experience with nature is transmitted orally by members of the same society, more specifically when people depend directly on the exploitation of nature to live (Balick and Cox, 1996; Hurrell and Pochettino, 2014). In spite of this deficit of local knowledge, the multicultural context of the city, the role played by the mass media (Huston

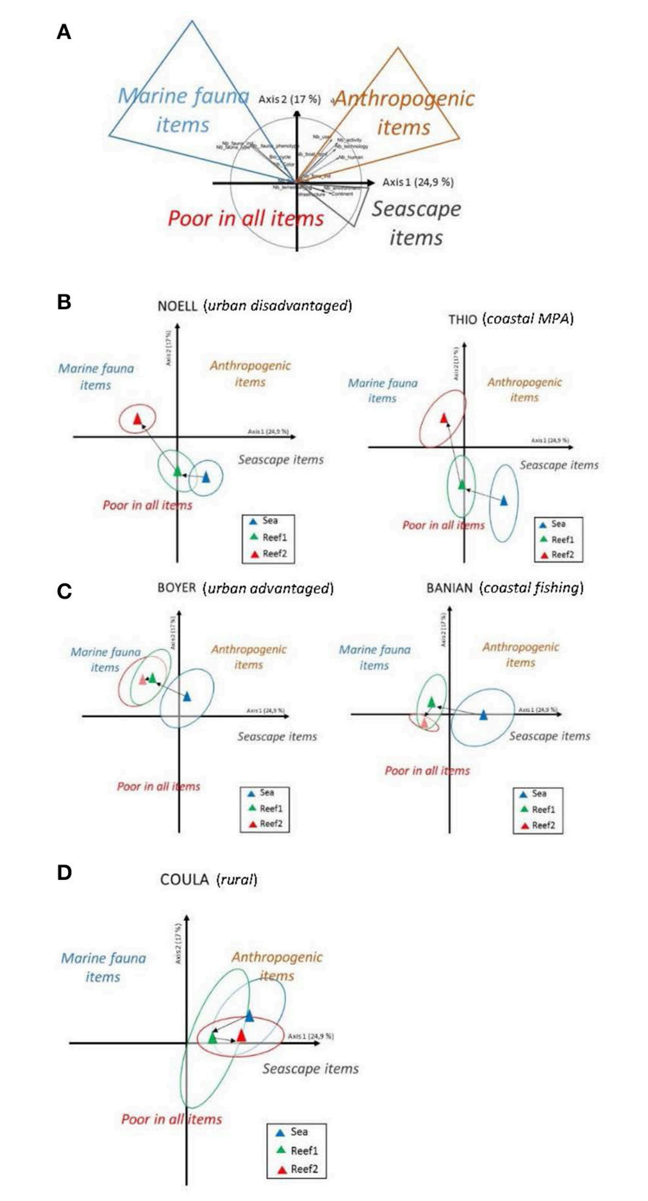


FIGURE 8 | Projection of the centers of gravity and confidence ellipses of the groups Themes*Schools on the first factorial plane of the PCA (blue: Sea; green: Reef1; red: Reef2). **(A)** Explanatory variables of the factorial axes 1 and 2. **(B)** Noell (disadvantaged school in urban neighborhood) and Thio (coastal school close to a marine reserve), **(C)** Boyer (socially-advantaged school in urban neighborhood) and Banian (coastal school near within a large fishing community), **(D)** Coula (rural school).

et al., 1999), the education programs in an advantaged school (Wagner, 2008) and the regular experience with coral reef of children whose family have recreational activities linked with the lagoon (Gonson et al., 2016, 2017), allows urban schoolchildren to acquire a lot of so-called scientific knowledge (McClatchey, 2005). Children in a advantaged urban environment show some knowledge of marine biodiversity in their drawings of the sea, and more than 50% of them drew human activities (mainly with boats). In a less-advantaged urban neighborhood, schoolchildren have drawings which are poorer in biodiversity or human activities linked with marine ecosystems, which could be reflecting their socio-economic context and the fact that they live beyond walking distance from the sea. This traditional knowledge is well-developed in a fishing community where schoolchildren demonstrate good marine ecological knowledge before the MARECO protocol, a trend observed in New Caledonia but also in coastal villages in Madagascar where the same protocol has been developed with Vezo communities (Ferraris et al., 2015; Stoica, 2016). This may be explained by classical ethno-ecological processes of knowledge acquisition (Ellen, 2006) in connection with close, longstanding and regular contacts of the children with the marine ecosystem through their family and the direct link between fishing activities and consumption. These regular contacts have the effect of tightening, increasing and homogenizing their ecological knowledge in a fairly extensive hybridization with information provided by the mass media and the school (Hurrell and Pochettino, 2014). Thus it seems surprising at first sight that schoolchildren in a coastal school near an MPA might make drawings which are poorer in biodiversity or human activities associated with the marine environment. This result can be explained by the fact that Thio is a mining village with adults working mainly in the nickel mines and where the marine protected area is recent and not connected directly to the village. In addition, the exploitation of nickel impacts the terrestrial environment with significant land erosion, making the coastal seawater turbid and leading to degradation of coral reefs (Chabanet et al., 2010), and unattractive for human activities. Finally, children in the rural school, located for our case study in the mountains, are characterized through their drawings by representations of the sea and the reef as seen from above, with people representative of the local community. They also make drawings where marine species are globally less represented, as they probably have trouble representing a marine ecosystem, mainly because they do not know it. This situation may explain the fact that in several drawings there are species such as whale or shark, more known through the media as emblematic species. In addition, local context or time circumstances may exacerbate a strong fascination, fear and imagination about the species, in particular, in our case, following an accident caused by a shark just before our intervention in the school and relayed in the media. This phenomenon was observed several times in Reunion in different classes involved in the research program where children drew sharks, the island having been impacted recently by several successive shark accidents (Lagabrielle et al., 2018).

The Impact of MARECO on the Children's Representations of Coral Reefs

Through the use of the MARECO protocol, the children developed a holistic perception that allows them to represent a healthy multi-colored coral reef (reflection of perceived biodiversity) and to connect it to their environment as demonstrated in our results. The colors of the reef come largely from corals that build the complex underwater seascape, in particular from pigments included in their algal symbionts

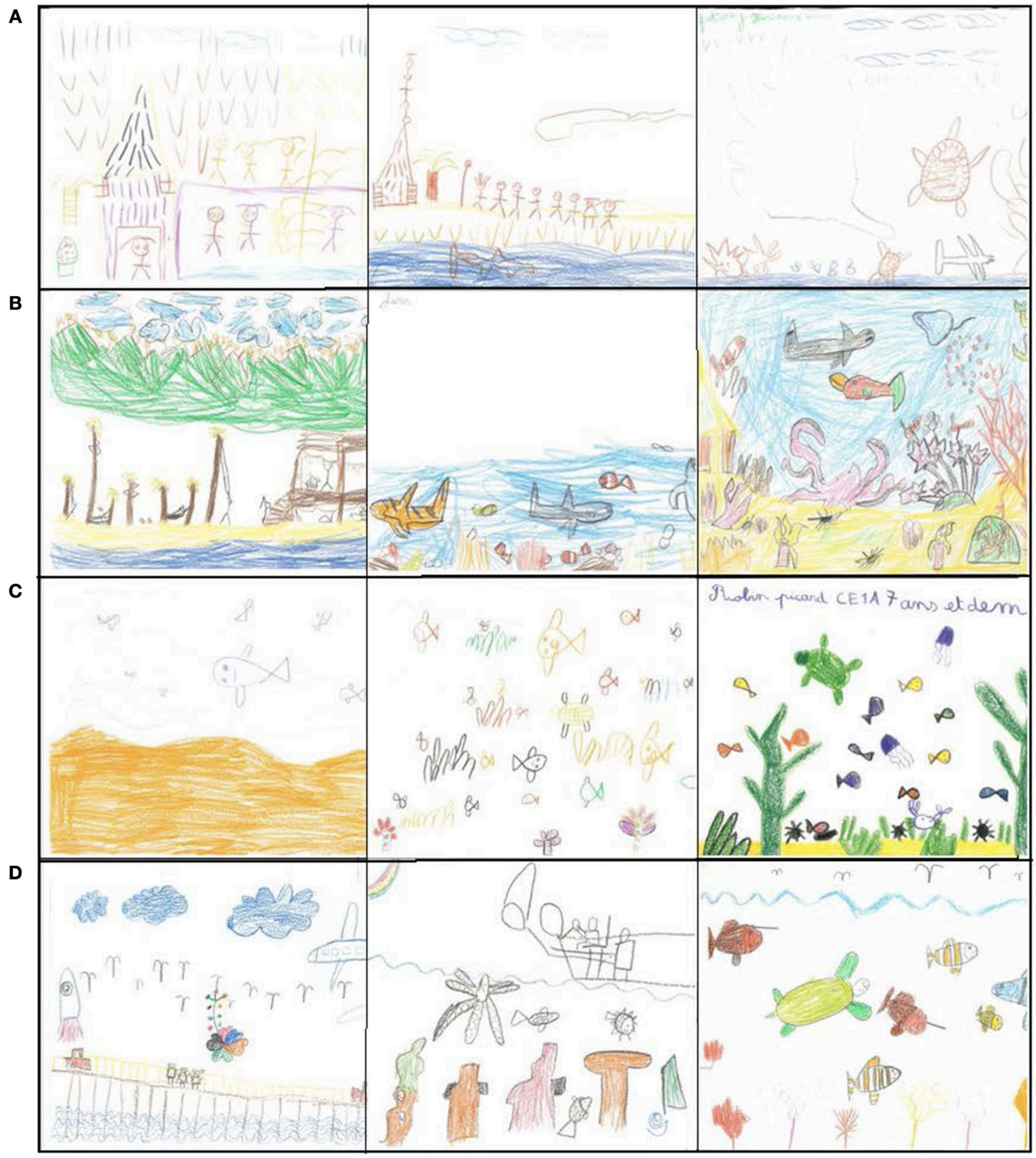


FIGURE 9 | Sequences of 4 Sea-Reef1-Reef2 drawings for 4 children (first name) who drew interesting features to highlight and scool indicated in parentheses. From up to below **(A)** Folialki (Noell), **(B)** Jaurès (Noell), **(C)** Robin (Boyer), **(D)** Yansi (Banian). Boyer: socially advantaged urban neighborhood, Noell: less advantaged urban neighborhood, Thio: coastal area close to a marine reserve, Banians: coastal area within a large fishing community, Coula: rural environment.

(zooxanthellae). When the concentration of pigments declines drastically (loss or expulsion of a major portion of zooxanthellae), the coral becomes pale and bleached due to the low concentration of pigments and the increased visibility of the coral's white skeleton. If corals do not regain their zooxanthellae, they die and are rapidly colonized by algae. Coral bleaching is a stress response usually associated with anthropogenic and natural disturbances (Glynn, 1991) which, when repeated though time, cause a "phase-shift" from coral dominance to algal dominance (Done, 1992; Bellwood et al., 2004). Degradation of coral reefs causes a reduction of coral cover, which is replaced by algae, but also of coral and fish diversity (Chabanet et al., 1997), with this reduction in biodiversity contributing to the loss of colors or their homogenization on coral reefs. Then the number of colors represented in the drawings is a relevant proxy of the marine biodiversity perceived by children after the MARECO protocol (**Figure 9**). Furthermore, the number of colors used by the children is also significantly related to "seascape items" (living and non-living environment variables), with the marine ecosystem often being represented in relation to its external environment (continental or atmospheric, sky, clouds, sun, rainbow, island, continent, etc.) with characteristics specific to the landscapes where schools are located (e.g., mountainous for Coula or Noell located on the heights of Nouméa). The presence of brilliant colors, which are generally factors of attractiveness (Reber et al., 2004), is undoubtedly part of the interest aroused by the picture book and its appropriation by children.

Finally, the use of MARECO has led to an overall decrease in human activities (mainly fishing and diving) in the children's representation of the environment, while their link with the coral reef was one of the messages conveyed by the games (mainly the board game). This decrease in human activities could be related to the impact of the awareness campaign, with the reef being associated with management (e.g., establishment of marine protected areas) and protection to decrease the impact of human activities. A majority of children adopted an underwater vision to draw the coral reef after the use of the toolbox (**Figure 9**). This can be explained by the visual influence of the images of the picture book, mainly by the poster included with it that the child could take home, but also by a focus brought by the teacher (poster display in class) or by the fact that the coral reef is a pictorial object that is rich and difficult to draw. Globally MARECO has a positive effect in all schools, but compared to each other, the impact is stronger in the less-advantaged urban school and the coastal school near an MPA where children have very poor knowledge or experience of coral reefs before the awareness campaign. Nonetheless, the cultural and socio-economic factors related to MARECO impact need to be investigated further in social sciences including all countries where the program has been performed to obtain more replications by school type for statistical analysis. Another general trend of our study points out a greater homogeneity in Reef2 drawings compared to Sea and Reef1 which show greater interpersonal variability in perception of marine ecosystems within or between classes. This result illustrates the impact of the awareness campaign or education on children's learning, leading to a "normalization" of the representation of coral reefs by children.

Specificities of MARECO

Playing games as a vehicle for learning is not a new concept (Annetta et al., 2009). If games are used in class, it is necessary for the teachers to assess them from an educational perspective to determine whether they can be integrated into their teaching practices (Britain and Liber, 2000). Some studies on the impact of environmental education campaigns exist with the use of questionnaires passed to children in schools (e.g., Lindemann-Matthies, 2002; Ballouard et al., 2011). Nevertheless, these studies are related to field practice, observation or investigation (especially *via* the internet) but not to the impact of games in schools. The originality of the MARECO toolbox comes from the evaluation of the impact of the awareness campaign through drawings made by young schoolchildren, but also from its development by scientists in association with an elementary-school teacher who created a booklet including activities for each of the three games. Therefore the concepts developed in the games are part of the school curriculum in life sciences and thus integrated naturally into the schoolchildren's learning process. According to our results based on the analysis of drawings characterized by quantitative variables, it appears that the effect of the toolbox is more pronounced for the picture book and card game, and more limited for the board game, even though children particularly appreciated the latter. This must be checked against the analysis of the interviews made in parallel with the children and teachers, but also with the commentaries made by the children about their drawings. Moreover, the timescale of the research program does not enable analysis of the real longer-term assimilation of the messages conveyed *via* the teaching toolbox, nor its impact on effective changes in representation, linked to knowledge or behavior. Nevertheless, one of the teachers taking part in the program in a disadvantaged urban neighborhood had children in fifth grade make drawings. These children had been initiated to MARECO in 2013, when they were in second grade. In the meantime, there had been no new intervention or teaching regarding the coral reef within the framework of the school curriculum. For the entirety of their drawings, there is clear persistence of the knowledge acquired 3 years previously. The diversity of the colors, wealth of the organisms drawn, knowledge of their names (brain coral, tabular coral, branch coral, crown-of-thorns starfish, etc.) show an evolution in representations with conclusive and lasting assimilation. Therefore MARECO has retained a positive impact on children over time, but this result has only been verified for seven children.

Another specificity of the awareness campaign is linked to the teachers' appropriation of the MARECO toolbox as an educational tool. Some of the teachers focused on the scientific learning it enables (initiation to the scientific approach, learning of new vocabulary, the acquiring of knowledge of ecosystems, raising awareness of environmental problems, pollution, climate change, etc.). Others leant on the toolbox as an aid for productions both scientific and artistic intended for the parents (paintings, sculptures, etc.), which also enabled the parents to join in learning the games *via* their children. In Mayotte, for instance, a teacher emphasized that when the picture book was taken home, this was the first time the parents and the children had ever done something together (Surugue, 2017). The teachers participating in the project proved to be proactive, independently developing tools to optimize the experiment, as much from their own experience as by elaborating a reflexive analysis on their way of using it. A case in point is how, for the board game, a teacher enhanced the playful side to the game by giving more weight to the role of the marine-reserve manager. Taking on the role of mediator, the pupil acting as the reef's "warden" assumed their responsibility in order to defuse conflicts, generating very constructive, enriching discussions for the pupils. Teachers' appropriation of the toolbox was also observed in other cultural contexts such as Madagascar, in coastal villages with limited means and electricity (Stoica, 2016).

This point underscores another interesting aspect of the toolbox, which is its transferability to southern countries owing to its simplicity of use (no need for electricity, a computer or the internet). This feature may be a brake for more developed countries where children tend to be drawn to more sophisticated games (video, internet network access, etc.) but this simplicity was intentional from the outset in view of the target for which MARECO's three educational games were developed, i.e., local coastal communities in southern countries in coral reef environments.

The MARECO toolbox thus appears to have fulfilled its objective of raising awareness of the coral reefs, with the caveat that humans are often, in this case study, absent from the representation of the ecosystem. This may be the reflection of the alarmist messages, unfortunately justified, of how humans disturb the reef, and which lend credence to the standpoint of nature protectionists to the detriment of the perspective of social conservationists (Caveen et al., 2015).

CONCLUSION

Our study demonstrates the performance of MARECO as a playful tool to transfer scientific knowledge to children. The results showed statistically that the drawings' representations of coral reefs before and after the awareness campaign are different, and that the numbers of colors used by the child for the drawings can be used as an indicator that the child has developed a more accurate holistic perception of the coral reef ecosystem, including marine biodiversity and seascape description. It appears necessary, however, to reinforce future awareness campaigns with messages boosting understanding of the place of humans in the ecosystem and how they can act for improved management of their activities (e.g., through marine protected areas). From a methodological viewpoint, it would be interesting in the future to develop an indicator related to ecosystem functions using the qualitative information collected on the drawings, e.g., the food chain, the number of interactions observed between species or the spatial representation of organisms in their environment.

In a context of Anthropocene where the degradation of coral reefs is accelerated in response to numerous anthropogenic drivers and climate change, the global challenge is to maintain the biological functions of the ecosystem and involve civil society in its management, including the young generation. As stated by Hughes et al. (2017), successful navigation of this transition will require radical changes in the science, management and governance of coral reefs. To strengthen the link between children and nature (in this instance, coral reefs), it is essential that children develop direct experience in order to develop an understanding of the biological world and implicitly in our case of the richness of coral reefs in terms of biodiversity but also interactions. To increase the effect of the MARECO teaching toolbox, it would be necessary for the children to see the reef in "real life" in order to integrate the notions acquired in a learning process at school. This gap could be at least be bridged by using movies and videos (e.g., https://www.chasingcoral.com) and interactive photography (e.g., https://www.google.com/streetview/#oceans). To be agents of change in a sustainable world, children must be engaged in a fun, rigorous, action-oriented and socially responsible learning process. Participatory approaches to learning for sustainability are recommended such as those developed in marine educational areas or Eco-Schools[2], which provide an integrated system for the environmental management of schools and involve children, teachers, managers and multi-level decision-makers.

AUTHOR CONTRIBUTIONS

JF, PC, GS, CS, and SC conceived the ideas and designed the methodology. GS, JF, CS, and PC collected the data. JF and CB performed the statistical analyses. All co-authors contributed to the manuscript originally written by PC, JF, and GS.

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[2]http://www.ecoschools.global/

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