Developing an Educational Tool to Model Food-Chains

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Abstract

The *Framework for K-12 Science Education* (NRC, 2012) and *Next Generation Science Standards* (NGSS Lead States, 2013) stress that in addition to disciplinary core ideas (content), students need to engage in the practices of science and develop an understanding of the crosscutting concepts such as cause and effect, systems, and scientific modeling. In response to these reform suggestions we developed an educational tool to be used to help teach students about models and the marine food chain. Our research was the validation of the tool as a legitimate instructional device. The research reported here outlines the process and provides science teacher and science teachers educators with an alternative for teaching this topic.

Key words: science education research, scientific models, food chains, educational tools

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Introduction

The *Framework for K-12 Science Education* (NRC, 2012) and *Next Generation Science Standards* (NGSS Lead States, 2013) stress that in addition to disciplinary core ideas (content), students need to engage in the practices of science and develop an understanding of the crosscutting concepts such as cause and effect, systems, and scientific modeling. In order to develop such practices, students must have repeated experiences that increase in complexity and vary in circumstances. They may engage with the actual phenomenon being studied or with representations and models giving students sustained opportunities to work, develop appreciation, and establish the existing interconnection among those ideas.

National (NAEP; NCES, 2014) and international (TIMSS; NCES, 2011) reports indicate that students in the United States are not doing as well on large-scale assessments as students in comparable countries. In response to the NGSS directive for students to be able to experience facets of disciplinary core ideas, crosscutting concepts, and scientific practices, the first author developed a dynamic model of a marine food chain that could be used by upper elementary students several times without redundancy. Scientific practices of creating and using a model, interpreting data, constructing explanation, and engaging in argumentation were an integral part of the experience. The model utilized a Jenga© tower in a game-like atmosphere requiring the students to use possible events that can occur within a food web to predict the effect such events would have on the system. A game is "a set of activities, involving one or more players…(with) goals, constraints, payoffs, and consequences…is rule-guided (and) involves some aspect of competition, even if that competition is with oneself" (Dempsey, Haynes, Lucassen, & Casey, 2002, p. 159). The use of games (Franklin, Peat, & Lewis, 2003; Gutierrez, 2014; Odenweller, Hsu, & DiCarlo, 1998) to help students develop scientific concepts is not new, but none were found that have developed a game-like model using the NGSS as a foundation.

Literature Review

Barman and Mayer (1994) determined that most teachers considered ecosystems, food chains, and food webs as important topics for students to know and believed that these concepts were somewhat easy for students to understand. The same teachers believed that these concepts were somewhat easy for students to understand (Barman & Mayer, 1994). However, more recent research reveals that students' ideas about these topics are usually filled with misconceptions (Umphlett, Brosius, Laungani, Rousseau & Leslie-Pelecky, 2009). For instance, students believe that changes in one trophic level will only affect another if they have a direct predator-prey relationship. Subtle interactions, which result in the balance of an ecosystem, are often not well understood by elementary and middle school students (Umphlett, et al, 2009). Ecosystems are complex systems that involve multiple variables, compound causes and consequences, and progressing structures which unfold in ways that cannot be seen by observers (Jacobson & Wilensky, 2006; Manz, 2012). As students move into middle and high school, they tend to think about individuals instead of populations, focus on animals, ignoring other groups of organisms (e.g. plants, fungi), and not think about the community as a system (Grotzer & Basca, 2003). Moreover, textbooks do not always explain the complexity of food chains and food webs (Barman & Mayer, 1994). In fact, many pictures in student texts have historically represented food webs with arrows pointing in the wrong direction, showing which organism got eaten as opposed to the direction of energy/matter flow (Schollum, 1983). Textbooks often assume that specific associations and generalizations about food relationships are abilities that students would continually establish on their own (Barman & Mayer, 1994). As a result, adults in the United States often lack basic knowledge and awareness of ecosystems and how they work (Tran, Payne & Whitley, 2010).

A possible way for teachers to help students understand these topics is through the use of games designed to show the intricacy of the systems. Classroom games have been shown to be an effective method of instruction to help develop content knowledge in physics (Anderson & Barnett, 2013; Clark et al, 2011), geology (Mayer, 2011), chemistry (Rastegapour & Marashi, 2012), and astronomy (Ruzhitskays, et al, 2013). Studies have found that the use of games in the classroom can lead to an increase in students' motivation levels (Baines & Slutsky, 2009; Pinder, 2008). Specifically, upper elementary students (Barab, Sadler, Heiselt, Hickey, & Zuiker, 2007; Kuo, 2007) and middle school students (Rowe, Shores, Mott, & Lester, 2010) expressed increased interest in learning science when presented with games. Games also can provide experiential, contextualized learning and can help develop metacognitive skills (Mayo, 2007). They can allow the players to be producers rather than consumers (Gee, 2003) as students make choices with consequences. Games that involve collaborative work "may act as a catalyst for change in students' self-efficacy" (Barab & Dede, 2007, p. 3).

Games may also be models or simulations of real, complex systems. This is important because the *Framework for K-12 Science Education* and *Next Generation Science Standards* (NGSS) stress that in addition to disciplinary core ideas, students need to be engaged in the practices of science and to develop an understanding of crosscutting concepts. Additionally, the NGSS (NGSS: Lead States 2013) highlight the importance of using tangible models as a way to help students understand both the nature of the scientific enterprise and disciplinary core ideas.

Scientific models are powerful tools that can be used by students to visualize scientific concepts, predict scientific phenomena and look for possible solutions. Even though there are several kinds of scientific models, most students consider them as objects to be interpreted, but not used to generate and test ideas (Lehrer & Schauble, 2006). Involving students in scientific modeling is important for helping them develop and evaluate explanations of the natural world (Baek, Schwarz, Chen, Hokayem & Zhan, 2011). De Ruiter, Wolters, Moore and Winemiller (2005) affirmed that, unlike the classic stone-arch metaphor for understanding food webs, Jenga towers are flexible structures that allow changes in species composition, attributes and dynamics, displaying characteristics of the ecosystems that are important to understand the complexity of the environment.

Theoretical Framework

We draw on two learning theories in our work: sociocultural constructivism and social languages. The theoretical framework used in both the development of the educational tool and this study is based in sociocultural constructivism (Luria, 1976; O'Loughlin, 1992; Vygotsky, 1978, 1986) and social languages (Bakhtin, 1981, Gee, 2004a, 2004b, 2008). During the 20^{th} century, several theories of cognition coalesced into a theory of learning which focuses on the construction of knowledge as situated within culture and language. This theory, sociocultural constructivism, emphasizes the importance of interacting with phenomena, ideas, and community in developing cognition. It forefronts the importance of cultural tools such as language, signs, and symbols produced within and by a group. Social constructivism then stresses the interactive nature of learning and the role of language as a tool for expressing what is known and for constructing new knowledge. In addition, the theory stresses the importance of others in helping the learner move from a novice to expert.

Bakhtin and Gee stress the social nature of scientific language. The current scientific way of talking and writing has developed over time within the scientific community and is specific to scientists. Words are given very specialized meaning or new words are invented as new phenomena are found. Gee (2004b) distinguishes between discourse (lower case 'd') that is generic and used in informal settings and Discourse (upper case 'D') that is highly specific and used by a sub-set of individuals. Scientists have developed a Discourse that is unique to science and can be further divided into sub-areas such as ecology. To be successful in school, students must learn the Discourse of science. Scientific Discourse can be acquired through interactions with language that occur during an apprenticeship. The science classroom may be the site of the apprenticeship.

Methods

The Peruvian Food Chain Jenga (PFCJ) was initially developed in order to engage upper elementary student in thinking about the disciplinary core idea of ecosystems (LS2 of NGSS); the crosscutting concepts of cause/effect (#2) and stability/change (#7); and the scientific practices of developing and using models (#2), constructing explanation (#6) and engaging in argument from evidence (#7) (see NRC, 2012, Box S-1, p.3). As with the development of an inventory or test, a process of determining the content accuracy and playability was a necessary pre-requisite to research concerning the effectiveness of using the tool for instructional purposes. However, unlike an inventory or test, classical measures of reliability (Cronbach's alpha) could not be performed to determine internal consistency. Therefore, three cycles of development and one cycle of student testing were used. In this article, we only report the development and validation of the game.

Development of the PFCJ

The development of the PFCJ began with the establishment of the ecosystem to be represented and what elements of the food chain to included. We chose the Peruvian marine ecosystem because the ocean off the coast of Peru is considered one of the most productive fishing areas in the world[1], it is highly impacted by human activities, and the aquatic and marine themes are often absent from K-12 curricula (Tran, Payne & Whitley, 2010). To illustrate concepts such as keystone species and top predators, we selected the Peruvian anchovy and the hammerhead shark, two species that are highly under pressure by contemporary practices such as overfishing and "finning".

The PFCJ utilizes the *Tower*, *Event Cards*, *Guide Sheet*, and *Placement* (Figure 1). The classic Jenga© game set has 54 blocks that are stacked to form a tower. We divided the blocks in seven groups, and assigned nine blocks for the first three trophic levels: zooplankton, phytoplankton, and anchovies; six blocks to the mackerel, squid, and mahi-mahi levels; and three blocks for top predator, the hammerhead shark. The remaining six blocks were labeled as 'wild cards' to allow for situations in which the player did not have an appropriate block. This block distribution was established to illustrate the abundance difference between organisms of different trophic levels. The resulting *Tower* represents the Peruvian marine food chain. However, it must be noted that the game is not proportional to the actual trophic levels.

Figure 1. Components of the Peruvian Food Chain Jenga©.

The single *Placemat* contains additional factual information that provides more in depth material that can be considered when making decisions about how to respond to the *Event Cards*. One side of the Placement is dedicated to content information, models and the role of models in science, challenges to the ecosystem, vocabulary, and the Peruvian Sea. The other side provides rules for planning the game. *Guide Sheets*, one for each player, give clues for the placement of the organisms from lowest to highest (producer to top predator) and provide a place for the students to record the tropic levels prior to constructing the tower. They also provide the students with a record that can be kept in their science notebook.

Event Cards provide situations for consideration by the students. The events or situations on the *Event Cards* are based on current issues that affect marine ecosystems and that are found in general-public media campaigns (e.g. *Take Shark Fin Soup Off the Menu!* campaign by Oceana, 2015). Topics for the *Event Cards* were also drawn from websites of international non-profit organizations and scientific literature. On the backside of each *Event Card* is a 'move' which tells the player to add blocks and remove blocks from specific trophic levels. These moves parallel the actual consequence of the event presented on the front of the card. As events occur, the *Tower* changes stability and eventually becomes so fragile that it collapses. The collapsed food chain is very graphic in its representation of what can happen in an ecosystem.

Data Collection

Data were collected in three phases. The first phase, determination of the *content accuracy*, utilized the help of college professors who taught biology, chemistry and science education. During the second phase, science education graduate students and biology teachers examined the tool for the *ease of use*. The last phase, *testing the tool*, engaged 4th and 5th grade students and their teacher in using the PFCJ and giving feedback.

Education Tool Phase I – Content Accuracy. The research team invited a small group of college professors from biology, chemistry, and science education to use the PFCJ prototype in the game format. The *Placemat* was examined for accuracy. *Events Cards* were drawn as directed by the instructions on the *Placement*, with the professor adding or removing a Jenga© block as deemed appropriate from the 'event' outlined on the card. At the completion of each player's turn, the event was discussed for correctness, density of language, confusing wording, potential reinforcement of misconceptions, and alignment with upper elementary core ideas. Suggestions were made for improving the accuracy and eliminating misconceptions. Appropriate changes were made.

Education Tool Phase II – Ease of Use. The next stage of development of the PFCJ was to establish ease of use of the PFCJ for non-scientists and to determine the value of each component of the model. This development phase involved two populations: science education graduate students and high school biology teachers. Both groups had signed Human Subject consents.

Four science education graduate students, all of whom had public school experience and one certified to teach English Language Learners, were asked to review the tool. Their task was to use the instructional tool in its current form and offer suggestions to improve the ease of use and the format of PFCJ components. They were particularly interested in the readability of the *Events Cards*, the appropriateness of the graphics on the *Placemat* and *Guide Sheet,* and the clarity of the instructions. The graduate students built the *Tower* to model the correct placement of trophic levels and played two rounds of the game. During the first round, players read the scenario and discussed the consequences that could result. However, when they looked at the moves offered on the reverse side of the *Event Card*, they could only remove a block based on one of the two consequences outlined on the *Event Card*. During the second round of the game, players removed blocks based on both consequences outlined on the *Event Card*. The merits of using one or both consequences were discussed by the group and notes were recorded. The decision was made to use both consequences in order to help model the complexity and fragility of the food chain.

Twenty-three high school biology teachers were introduced to the PFCJ as a way to review food chains with general biology students. They worked in groups of four, following the instructions as if they were students. The *Tower* was built to show the correct order of the trophic levels and *Event Cards* were drawn, read aloud, consequences predicted, and blocks removed or added as predicted. After all teams had completed one round, the teachers were instructed to think about and discuss how to improve the experience (notes were taken at each table). They were asked to critique the instructions, the level of vocabulary, and usefulness as a way to present/review food chains, cause and effect, systems, and models. Audio recorders were placed at each table to capture the conversations. Table groups then shared with the whole room, with a lively discussion of what was most valuable and lest valuable. Notes were taken by two of the authors and small changes were made.

Education Tool Phase III – Testing the tool. The third phase was conducted at a local elementary school. The participants in this phase consisted of the students in one 4th grade class and four 5th grade classes (N = 89). The research team helped monitor four of the classes but the last class was conducted completely by the classroom teacher. All groups signed consent for media and data use. In each class, students were divided into groups of three or four to complete the PFCJ lesson (Figure 2).

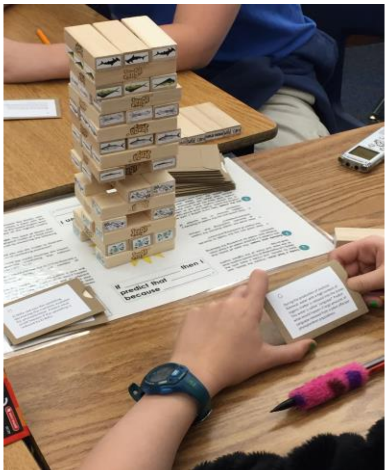


Figure 2. Students engaged in PFCJ

Researchers collected both quantitative and qualitative data during this phase. Quantitative data included student responses to a questionnaire and a time-stage chart. The questionnaire was a 28-question Likert-scale survey based on Gutierrez (2013) previous work. The questionnaire was divided in five categories 1) goals and objectives/clarity of purpose, 2) design of the tool, 3) organization of the activity, 4) rules and playfulness, and 5) usefulness of the lesson. After every section a place for comments was provided. Qualitative data included researcher field notes, responses to open-ended questions, a 'What I did/What I learned' sheet filled out by the students, audio recordings of students interacting with the PFCJ, and an informal discussion with the classroom teacher.

Data Analysis

Notes from Phase I were reviewed for content accuracy. Audio and research notes from Phase II were loosely analyzed for comments that occurred frequently or that resonated with the research team about what was useful and what was not. Phase III required the calculation of mean scores of the responses for the students' questionnaire (Table 1) to determine student opinion of the activity and a chart to show the time span for each phase. Qualitative analysis for the student responses used a modified constant comparative design (Glaser & Strauss, 1967). Each research team member read and coded the open-ended responses for emerging themes. Research themes were compared and collapsed into two categories.

Results and Discussion

The result of each phase is presented below. The different phases take into account recommendations from content experts, science education graduate students, classroom teachers, and elementary students. Because each phase was designed to provide input from dissimilar groups on different aspects of the tool, the outcomes vary. With each phase of the testing, results were incorporated into the PFCJ.

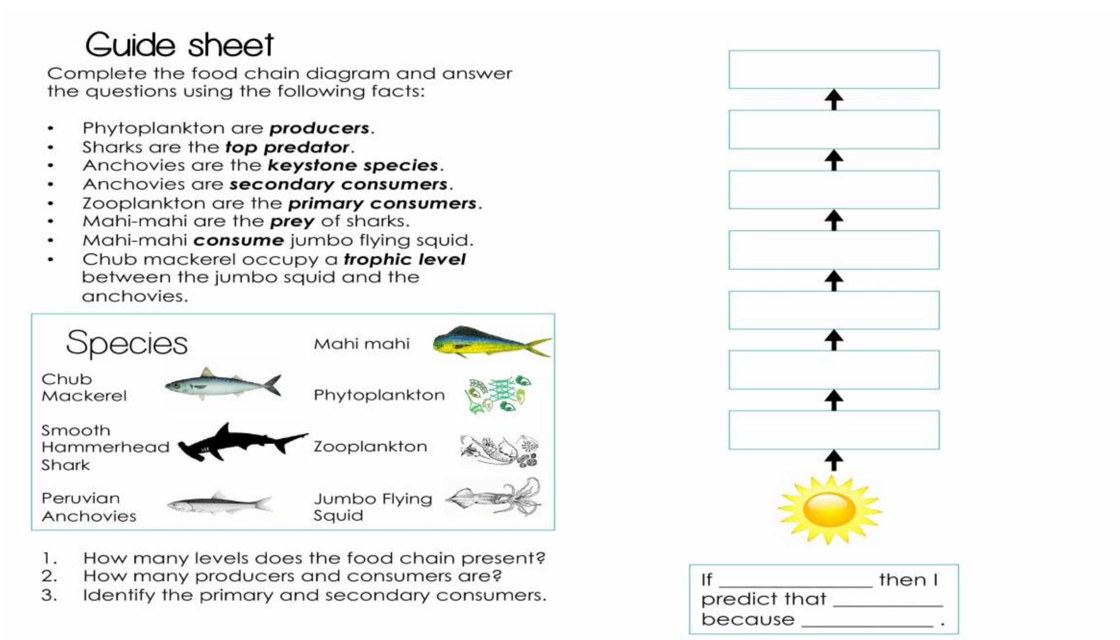
Phase I content discussion

The college professors agreed that the model was appropriate even though the trophic levels were not in proportion. They discussed various ways of wording some of the cards but did not make any substantial content changes. The small changes in wording were made and approved by the content experts. Thus, content validity was established and the tool moved to the next level of testing.

Phase II educational use of the tool

The science education students were concerned with the alignment of the PFCJ to the national standards and with ease of use for students of low reading and/or language ability. They discussed the value of the *Placemat* as a source of information and wording of the instruction for building the initial *Tower*. They suggested addition of the species picture to the *Guide sheet* (Figure 3) and a sentence starter on the *Guide Sheet* and *Placemat*.

In response to the suggestions, the research team inserted the prompt sentence "If ___ then I predict that ___ because ___", on the *Placemat* and the *Guide Sheet*. Using sentence prompts can help reinforce scientific language and provide the students with giving a reason for the prediction/claim that they made. In addition, pictures of the species were added to the *Guide Sheet.*



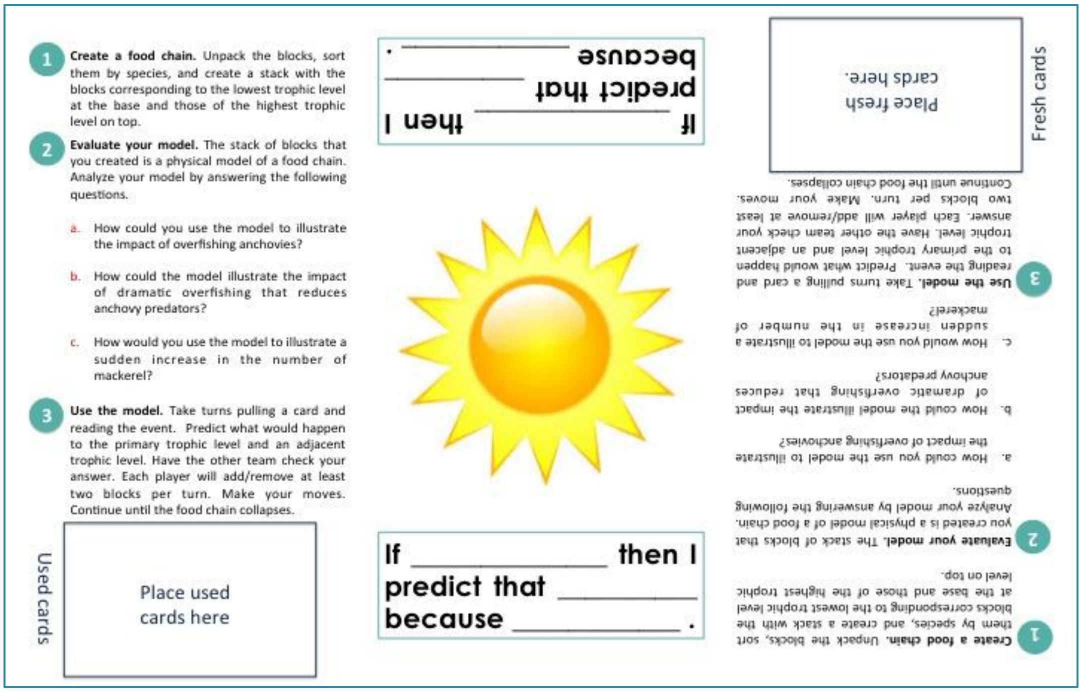


Figure 3. Guide Sheet and Placemat

We held a post-activity discussion with the teachers. Most of the teachers had positive comments about the tool and stated that it could be used as an introduction to the unit or reinforcement/review at the end of the unit. High school teachers said they could use the tool as a refresher for students even though it was designed for upper elementary. Some teachers also indicated that with small additions the tool could be used to explain energy loss in a food chain, natural selection (easy to remove blocks can be considered "weak" individuals in the population), invasive species (adding 'wild cards' to represent the introduction of exotic species), and it could even be used as the start for developing their own activity.

Regarding the *Placemat* and *Event Cards*, the biology teachers did not have any modifications. However, some teachers suggested a vocabulary handout for teachers. Most of the teachers suggested a worksheet were students in groups could write their predictions. Conversely, other teachers felt that part of the value of the tool was the open discussion and argumentation that could occur as each student took his/her turn. We also added new vocabulary to the Teacher's Handout.

Phase III post activity student responses to the tool

Quantitative. Overall, students had a positive opinion of the PFCJ as seen by their scores on the questionnaire. Section 4, rules and playfulness, got the highest average mean with 4.67. The question with the highest rating was also on this section (#23: 'participating in the activity was fun' = 4.878). This indicates that the students found the tool to be fun and understandable. In contrast, Section 3 (organization) got the lowest rating (4.23). The lowest question in the section addressed the amount of time needed to finish. The result seems to indicate that students wanted more time. Even so, the overall result was still 'very satisfactory' with the organization. The question with the lowest rating was on Section 1, #6: 'the activity helped me remember concepts and vocabulary' with 3.84. Almost as low was #27: 'participating in the activity helped me establish better relationships with the members of the group' from Section 5. It should be noted that students felt the activity helped them review the topic (4.58), was a productive use of their time (4.63), and made them think about what they were doing (4.57).

Table 1. Student evaluation questionnaire. The scale was from 1 to 5, and had the following information: 1, strongly disagree; 3, neutral; 5, strongly agree.

		N° of students who answered	Mean
	Section 1 - Clarity of purpose		
1	The purpose and reason for the activity were fully explained to me	89	4.31
2	The goals and objectives of the activity were clearly stated	89	4.38
3	The activity made me think about what I was doing	89	4.57
4	The activity encouraged me to work with other students	88	4.30
5	The activity allowed my group to discuss key concepts	89	4.25
6	The activity helped me remember concepts and vocabulary	89	3.84
	Average mean		4.28
	Section 2 - Appropriateness of design		
7	The placemat is the right size	86	4.56
8	The Jenga tower size is appropriate	86	4.74
9	Having a two-side placemat is helpful for the players	87	4.21
10	Having the animals on both ends of the blocks is helpful for the players	86	4.76
11	The pictures on the placemat and the Jenga blocks are representative of the topic	86	4.55
12	The placemat does not rip or tear easily	87	4.68
13	The placemat size is easy to move around	86	4.17
14	The Jenga set size is easy to move around	86	4.07
	Average mean		4.47
	Section 3 - Organization		
15	I easily understood the directions	85	4.15
16	The activity emphasized key points of the topic	84	4.46
17	The vocabulary used was just right to my level of knowledge	84	4.27
18	The number of prediction/event cards was just right	83	4.24
19	The amount of time needed to finish the activity was just right	84	4.04
	Average mean		4.23
	Section 4 – Rules and playfulness		
20	The activity encouraged friendly competition and cooperation	83	4.68
21	The activity allowed everyone to play fairly	83	4.60
22	The rules of the activity allow me to make some choice	82	4.51
23	Participating in the activity was fun	82	4.88
	Average mean		4.67
	Section 5 - Usefulness of lesson		
24	The activity helped me review the material	81	4.58
25	The activity encouraged me to dig deeper into the subject matter	80	4.45
26	Participating in the activity is a productive use of time	79	4.63
27	Participating in the activity helped me establish better relationships with the members of the group	79	3.87
28	I would recommend the activity to my friends	79	4.54
	Average mean		4.42

In the comments sections of the questionnaire students expressed a positive attitude for the game. One third of the students considered it a 'fun' activity. Another common comment was about the number of cards in the game and the time needed. Students thought there were too many *Event Cards* and that the time was not enough. However, we considered this downside may be an opportunity for students to play the game several times getting new 'questions' every time and getting different outcomes, getting a more complete understanding of the lesson.

Qualitative. Additionally, each student completed a "What I did/What I learned" handout. The coding separated the comments about learning into two themes: those too generic to give any real indication of what was learned and those giving specific reference to what was learned. Many of the comments about what they learned were very generic. For example:

I learned about the food chain.
We learned about producers and consumers.
I learned new vocabulary.
I learned about the aquatic chain in Peru.

However, 15 of 50 (30%) student responses were highly specific about what was learned by using the model. For example, students wrote:

I learned that harming one species could bring down everything.
I learned that the food chain is not as sturdy as I thought.
I learned that if something at the bottom of the food chain is moved then everything above is affected.
I learned that even if you remove something small it can affect the whole chain.
I learned that you should be careful of your environment.
I learned that the anchovy is a key specie.
I learned that animals could increase or decrease if one thing (animal) decreased or increased.

These comments helped the research team determine that use of the PFCJ activity appeared to help students with content knowledge and crosscutting ideas. While the generic comments do not give indication that the students learned any specific content, they do give indication that students were able to connect use of the model to the concepts being taught. The highly specific comments indicate that the model may serve as a useful tool to help students visualize how changes in one trophic level may affect the entire food chain.

Lastly, when given the opportunity to tell how they would improve the game, no student offered improvements. Several students wrote that they loved it just as it was presented. One student wrote, 'NO improvement needed'. Even the length of time necessary to complete the tower building and round one of play did not get criticism from the students.

Implication

The goal of this study was to field-test the educational tool for content accuracy, ease of use, and student approval. Content accuracy is considered important because resent research reveals that students' ideas about food chains are usually filled with misconceptions (Umphlett et al., 2009). In addition, researchers have also found that textbooks do not always explain the complexity of food chains and food webs (Barman & Mayer, 1994). Moreover, The *Framework for K-12 Science Education* (NRC, 2012) and *Next Generation Science Standards* (NGSS Lead States, 2013) stress that in addition to disciplinary core ideas (content), students need to engage in the practices of science and develop an understanding of the crosscutting concepts such as cause and effect, systems, and scientific modeling.

Based on student and teacher comments, we consider that the PFCJ is ready to be used as an instructional tool for upper elementary students. However, such a tool cannot be used unless it can be demonstrated that the content learning by students taught using the tool is equal to or greater than the learning by students taught the same content in a traditional method. At this writing, the research team are examining how use of the PFCJ impacts 5th grade student conceptualization of food chains compared to traditional teaching methods, and have collected data using an intervention group and control group design within a 5th grade classroom.

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Notes

[1]Peruvian marine ecosystem represents <0.1% of the total ocean surface but produces around 10% of the total fish catch as cited in Chavez, Bertrand, Guevara-Carrasco, Soler & Csirke, 2008.

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