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Encouraging creativity in mathematics and science through photography

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Based on the results of a survey of the science and mathematics students at our university, we observed that students do not consider mathematics and science to be creative endeavors, though the traditional artistic disciplines rank high in this regard. To address this problem in perception, the authors used photography as a means to encourage students to find the deep-rooted connections between science and mathematics and the arts. The photography project was used in a formal classroom setting as well as an outside activity, i.e. in a more informal setting. In this article, we describe the project and its outcomes.

1. Introduction

The role of creativity and the importance of its recognition and cultivation in the sciences have been discussed extensively in recent times (Birchmore, 1988; Garfield, 1989a,b; Neumann, 2007; Nickerson, 2009; Roberts, 2009). Mathematics and science education for the most part tends to be a very linear process where deductive reasoning is emphasized (Felder, 1988), whereas creativity is seen to be a nonlinear process and involves a more inductive approach to learning. The literature on creativity is vast and dates back to centuries and spans different cultures. While creativity itself has remained a somewhat elusive notion, there has been a need to understand it better to see if it is inherent or can be cultivated. The physicist David Bohm (2004) relates creativity to the idea of 'originality' which he states:

> . . . is very hard to define or specify . . . it will be best to hint at it . . . One prerequisite for originality is clearly that a person shall not be inclined to impose his preconceptions on the fact as he sees it. Rather, he must be able to learn something new, even if this means that the ideas and notions that are near and dear are overturned.

The literature on creativity from psychology and education scholars is even more vast. Based on the works of MacKinnon (1975), Simonton (1984,1999) and Sternberg (2001), Spendlove (2005) identifies several qualities of a creative person, namely:

> [1] intellectual curiosity, [2] commitment, [3] courage to be different, [4] independence in thought and action, [5] strong desire for self-realization, [6] strong sense of self, [7] openness to impressions from within and without, [8] attracted by complexity and curiosity; [9] high capacity for emotional involvement in their investigations; [10] intrinsically motivated.

For the purpose of this artice, we will follow Bohm and define 'creativity' to be akin to the notion of 'originality' and the ability to 'overturn paradigms in thinking'. We do so both for its ease of comprehension and its relevance to the project described in the paper. It must be noted however, that in the literature, creativity is commonly associated with a major shift or revolution in thinking (Sternberg, 2001; Bohm, 2004). However, we feel that an absolute definition such as this is not required. In the context of education particularly, a shift in one's own thinking or a revelation, however small, would still count as a creative act. Creativity might therefore be considered as having varying degree associated with it depending on the sphere of its influence (Munakata and Vaidya, 2011, manuscript submitted for publication).

This article describes two art-science projects that encourage students to be creative by considering the mathematics and science represented around them in their work and finding the blending of art and science in it. Similar to Oldknow (2009) and Aydin and Monaghan (2011), these projects involve the use of photography. The motivation for these projects came from our notion that students in science and mathematics often do not view their work as being creative. To this end, in order to determine the extent to which students consider creativity to be an important aspect of science and mathematics, we conducted a pilot study. Students were first asked to identify the most creative activity with which they have been involved. We then asked students to rate each major discipline on a scale from 1 to 5, with 5 representing the degree of creativity involved in the activity they identified. Based on data collected from students in the College of Science and Mathematics at Montclair State University, we found that students regard science and mathematics as requiring less creativity than many other disciplines (Table 1).

Perhaps not surprisingly, students rated the arts the highest in creativity. Of the sciences, the applied sciences (medicine, engineering) have higher mean scores than the pure sciences (biology, chemistry). Mathematics has a score of 3, indicating that it lies firmly between the two extremes, but again, it ranks lower than the applied fields (computer science and physics). It is, however, worth noting that mathematics has the highest standard deviation.

TABLE 1.

$N = 218$	Mean (SD)
Music	4.35 (0.94)
Dance	4.19 (1.00)
Theater	4.18 (1.02)
Visual Arts	4.17 (0.98)
Medicine	3.69 (1.21)
Engineering	3.54 (1.17)
Philosophy	3.38 (1.16)
Physics	3.31 (1.19)
English	3.28 (1.01)
Biology	3.23 (1.12)
Computer Science	3.23 (1.20)
Psychology	3.03 (1.06)
Physical Education	3.00 (1.22)
Mathematics	3.00 (1.22)
Chemistry	2.93 (1.20)
Economics	2.22 (1.09)
History	2.11 (1.00)

One way to encourage creativity in science and mathematics and to call upon different learning styles is to challenge students to see science and mathematics in everyday situations. Research points to the fact that students learn differently (Schmeck, 1988; Felder, 1998; Cassidy, 2004; Kolb and Kolb, 2005). The three major learning categories identified in a variety of disciplines include visual, auditory and tactile learners (Dunn, Beaudry and Klavas, 2002; Conway, 2005; Lujan and DiCarlo, 2006). These studies indicate that while we perhaps invoke different styles on different occasions, we possess a natural predisposition towards one of these. Therefore, we feel that effective learning occurs and creativity is best invoked when teaching is done in a manner as to appeal to the different forms of learning; our hope is that by invoking different senses in the learning process, we allow for all students to learn effectively, actively, and also from each other. Such an avenue for group participation and community learning is often lacking in typical physics and mathematics courses, which are predominantly lecture style.

In this article, we describe two activities (an exhibition and a class assignment) developed for two different audiences—undergraduate science and mathematics students and in-service mathematics teachers—to encourage creativity in science and mathematics. Through the project, students are asked to consider evidence and representations of science and mathematics in their everyday lives, record it, and explain the science and mathematics involved.

Both assignments involve the use of photography. In the first part of this article, we will describe an assignment designed for a graduate-level course, Contemporary Teaching of Mathematics, a course for pre- and in-service middle school and high school teachers. We will then describe the Physics and Art Exhibition, which was open to all science and mathematics students.

2. Photo contest for teachers

The Contemporary Teaching of Mathematics course is a masters-level course for pre- and in-service mathematics teachers (hereafter referred to as students). Discussions and assignments for the course include topics such as interdisciplinary instruction, history of mathematics education, meaningful uses of technology, teaching for social justice and teaching diverse learners. The photo contest is the culminating assignment for the course: students have one month to prepare their submissions with the actual photo contest taking place during finals week. The assignment challenges students to be on the lookout for images of mathematics around them and to capture those images through photography. Students are asked to take the photograph(s), analyse the mathematics underlying one of them, and develop questions that promote problem solving based on that photograph.

The objectives of the photo contest assignment are to encourage students to identify mathematics in their natural environment, to delve deeply into the mathematics represented in that photograph and to consider using such evidence as motivation for the learning of mathematics in their own classrooms. As educators, we are constantly seeking connections between the content we teach and our everyday environment: this assignment formalizes that process and allows students to share ideas with other practicing and prospective teachers. The development of the assignment was inspired by the Physics and Art Exhibition (see following section for details), the Mathematical Lens column of the Mathematics Teacher and the Mathematics Association of America's Found Math Gallery.

2.1 Assignment guidelines

Students are encouraged to take many photographs and to select one that best exemplifies the spirit of the assignment. Certain restrictions are stated in the assignment guidelines. For example, photographs must be taken by the student during the semester. In other words, they cannot be ones that they dig out of the family album or ones taken by a photographer (professional or otherwise). The photographs must be of the original object (or phenomenon) and not of a magazine cover, for example. The photographs should be printed or produced on paper no larger than 8 ½ × 11, and be of high-quality resolution. Photographs may be in colour or black and white; digital or print (taken with a disposable camera, for those who don't own a digital camera); and of an animate or inanimate object. Major alterations of the photograph are not permitted, but the photographs may be drawn on using editing software or writing implements if all that is being done is adding lines, pointing out features, or adding text. The instructor (MM) encouraged students to look for original examples by listing some typical examples (to stay away from) such as price tags and receipts.

Once they have decided upon the photograph to be submitted, students are asked to analyse the mathematics behind it. They are asked to write at least four thought-provoking, multi-step mathematics problems. The mathematical topic may be from any content area but must be appropriate for middle school, high school, or college students. Students also prepare proposed solutions for each problem. Open-ended problems are encouraged, but the solutions should include at least a predicted response from middle/high school students. Finally, each student prepares a poster that showcases his/her photograph and the mathematics problems. On the day of the photo contest, we display the posters around the room and use the time to view and judge the posters.

In addition to the photograph and the four problems (with their solutions), each poster should include a description of the photograph. The descriptions include a title; date and location of photograph taken; the mathematics topic being represented; intended grade level; and a one-paragraph description of how the photograph can be used to motivate the learning of mathematics in the classroom. The following example of the photograph description (based on the photograph in Appendix Figure A1) is included in the guidelines:

- A New York City 'No Parking' sign
- Taken on 79th and Broadway, New York City, 2 October 2010
- Topic: Symbolic Logic
- High school geometry, computer science, or college discrete mathematics courses.
- This photograph can be used in geometry classes in tandem with lessons related to writing proofs or computer programs. It encourages students to use logical reasoning in their everyday lives and challenges them to use symbolic or formal logic to analyse ambiguous situations. Though the focus of my problems is symbolic logic, students may also use other representations, such as Venn Diagrams to analyse the signs.

2.2 *Assessment*

Since this is a photo *contest*, the posters are 'judged' by students in the class. The rubric used to judge the posters is attached as Appendix Table B1. Students' grades for the project are comprised of the average scores from their peers' evaluations (50%) and my (author MM) evaluation (50%). The peer rating of the posters is completed as students view the posters during class. The posters were evaluated using the same rubric, but were assessed outside of class, as overseeing the overall judging process made it difficult to spend sufficient time on each poster. At the end of the judging period, the scores were quickly tallied and (mathematics-inspired) prizes were awarded to creators of the top three posters. In the case of a tie, the instructor (MM) acted as the tiebreaker.

2.3 Sample posters

Students' posters varied in content. They ranged from a photograph of water droplets on a tablecloth [Appendix Figure C1(a)] to one of a wedding cake [Appendix Figure C1(b)]. Several represented sports-and play-related themes such as a ice hockey rink, the trajectory of a basketball, and a neighborhood playground. Others found mathematics in patio tiles, wedding cakes, and bicycle racks. The following are some of the questions posed by the students.

2.3.1 Water droplets on a tablecloth [Appendix Figure C1(a)]

(1) Create a coordinate plane overlap of the image and determine equations that represent the bubbles.

(2) Suppose there is a thirsty ant walking on the table. Suppose the ant wants to find the shortest path between the bubbles. Compare the cost (measured by distance) of the circuits that arise from different traveling salesperson algorithms.

(3) What is the probability that a dropped contact lens will land in a bubble of water?

2.3.2 Wedding cake [Appendix C1(b)].

(1) Assuming that the icing is placed onto the cake after the cake has been built, determine the amount of icing needed to cover the visible surface of the cake, in square inches.

(2) This cake arrived in a cone-shaped box. If the cone comes to a point 10 inches above the top of the cake, what will the radius of the cone be at the bottom of the cake?

Most of the objects and phenomena photographed were refreshing alternatives to the typical situations described in mathematics books, such as maximizing fencing or modelling price reductions.

2.4 Reactions to assignment

Students were asked to provide their reactions to the assignment on a short survey given after the event. They were asked to describe what they learned from the assignment from the standpoint of the photographer; what they learned from the standpoint of an exhibit attendee; and their overall impression of the process undertaken for the project. Students generally found that mathematics was 'everywhere', but that it was a challenge to represent those situations mathematically. They noted how much of the mathematics in the 'real' world they had not noticed before and were impressed with the high level of creativity represented. One student wrote '(I learned that) people are extremely creative and still like doing creative projects like this even at the master's level.' Another wrote that it was 'nice to see everyone's mathematical 'artist' come through'. Others noted that the project made them 'think outside the box' and promoted critical thinking.

3. Physics and art exhibition

The first of the annual Physics and Art exhibition at our university was held on 21 April 2010, at the College of Science and Mathematics (CSAM). The event showcased photographs taken by undergraduate students in CSAM. The event was held again on 23 March 2011. This time, the event was open to the entire university.

3.1 Guidelines for contributions

The photos had to be creative and artistically done on a physics-related theme, and the students were asked to identify and elaborate on the science behind the art. We received about 30 entries from students in different disciplines each year. The students were also asked to write a short descriptive piece about the art. The writing could discuss when, why and how the picture was taken and if possible what art–science connections they saw in their photographs. Two prizes were awarded upon judging by a jury comprising of faculty from Physics, Photography, English and Philosophy. Some of the entries are now archived on the Creative Research Center website of Montclair State University (http://www.montclair.edu/creativeresearch/studentcenter/photoexhibition.html). Some of the pictures are also shown in the Appendix Figure D1 along with the write-ups.

3.2 Art–science lectures

In addition to the Photo Exhibition and contest, there was a keynote lecture on both occasions. The lecture in 2010 was given by Prof. Jun Zhang from the Department of Physics, New York University. He spoke about the very artistic approaches to fluid flow visualization and his related research. During the second event, in 2011, Olivia Fermi, a photographer, behavioral scientist and grand-daughter of the Nobel laureate, Enrico Fermi, spoke about her grandfather's legacy, the atom bomb and those affected by it—told through family and personal photographs.

3.3 Objectives

The idea behind the events of the day were two-fold: the art exhibition which was student-oriented gave the students a chance to participate in an art-science creation while the talk was meant to reinforce the relationship between art and science through the work of some leading expert. Both these events got us all in the right frame of mind to discuss the deep connections between art and science and to reveal the sciences as a very creative enterprise, a distinction commonly and erroneously attributed to the artistic disciplines. The exhibition was inspired by the Gallery of Fluid Motions contest organized by the American Physical Society at their annual Fluid Mechanics meeting. This contest is however more research oriented and geared primarily for advanced researchers.

3.4 Reactions

Conversations and the general public mood during the event clearly indicated excitement over the photographs and appreciation for the theme of the day. Participants were encouraged to fill out a survey indicating their impressions of the event. The results of our surveys clearly indicate this attitude. A total of 54 surveys were collected over the 2 years.

A question in the survey conducted in year 2 (27 total respondents) asked; *What is the most creative activity you have been involved in?* to which an overwhelming 20 respondents gave examples in the arts (drawing, painting, photography, theater, writing, etc.) while nine surveys indicated scientific activities. Some of the respondents indicated both art and science.

A second question asked*: How creative an activity is it doing mathematics and science [compared with the most creative activity you have involved in]?* to which ten respondents indicated that 'creativity was the same in art and science', five indicated that 'science was more creative than arts' and one indicated that 'art was more creative than science'. While we do not have sufficient data to verify the statistical accuracy of the answers obtained for the above two questions, a different study performed by the authors on students from CSAM which asked them to list on a Likert scale of 1–5 how creative they thought various disciplines were, renders more reliable results. The responses, based upon a pilot study of 218 students, is shown in Table 1 in the introduction. It is immediately clear from the tabulated responses that the traditional artistic disciplines rank higher than the sciences and mathematics. Among the scientific disciplines, mathematics received the lowest scores (although there was a lot of variation in the responses as indicated by the standard deviation). What we infer from these surveys and from informal follow-up discussions with some of the respondents is that for many students, classroom science, especially when taught traditionally, feels devoid of any creativity.

To the question: *Has this exhibit changed your views about creativity in the mathematical and physical sciences?* 23 respondents, including undergraduate and graduate students, visiting high school teachers and university professors responded positively and several gave specific examples of what appealed to them and changed their perspectives. Of the remaining surveys, 25 did not respond to the question and 6 respondents stated that they were always aware of the art–science connections and the event did not change their minds.

The importance of such informal events tied to the classroom cannot be underestimated. They can be extremely beneficial in conveying essential ideas which might be difficult in the traditional classroom due to pressures associated with grades. Additionally, even the elementary mathematical treatments of topics in physics is seen by many students as being very burdensome due to previously instilled fears about mathematics and science. While these events remained outside the classroom, students in the author's (AV) class were asked to participate for extra credit. It is very much possible, in fact, to have students do this as a formal class project and devote a class to the discussions surrounding the exhibition and talk, as has been discussed in the previous section. The accessibility of such a project to all students is perhaps its greatest advantage. While not every photograph may be captivating, all students are able to participate in exploring connections between the sciences and creativity in a novel way.

In the true sense of 'creativity' (as we have chosen to define it), these events provide the opportunity for students to change their paradigms about the nature of science learning. More often than not, we found the students surprised to find physics hidden in the pictures that they took. No matter what the sphere of influence of a creative work, its influence remains worthy of notice and allows for greater and higher level creative acts in the future (Munakata & Vaidya, 2011, manuscript submitted for publication).

4. Conclusion

These two assignments are just two ideas that encourage students to seek connections between the sciences and everyday life through photography. Mathematics and science topics are replete with such connections—many other possibilities for similar-themed projects are possible. For example, to motivate topics in calculus, instructors might ask students to create a photo-journal of representation of calculus ideas or to create a video showcasing an idea from calculus. Another similar example has recently been discussed by Aydin and Monaghan (2011).

Whether the course is one belonging to a traditional mathematics or science discipline, or even a teacher education course, it is much more meaningful to have students seek these connections for themselves rather than the instructor or textbook pointing it out to them. What we have strived for through both of the photography and math-science initiatives has been to have students actively and independently find meaning in science and mathematics; their own meaning which cannot be invalidated. The student experience in these events can be compared to the true nature of scientific and mathematical progression where the disciplines are advanced by trial and error and by appealing to ones intuition as often as to pure logic. While a more rigorous and detailed study is required, we are optimistic about our experiments which clearly points to a clear benefit of such an open ended approach.

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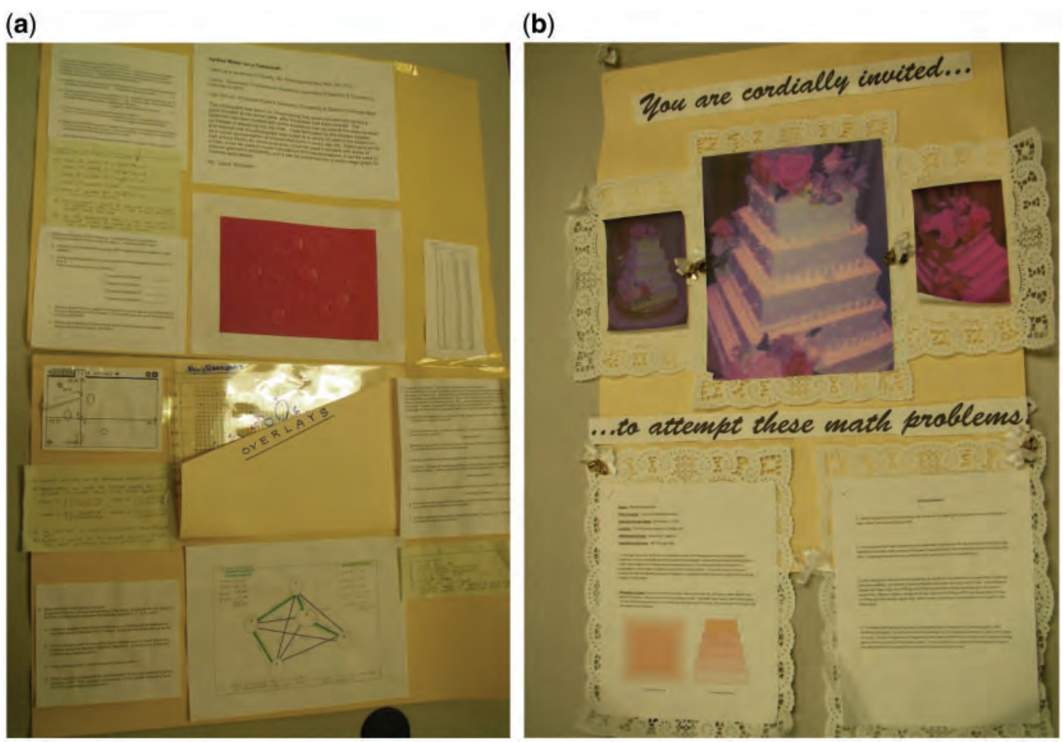
Appendix Table B1. *Rubric for photo contest*

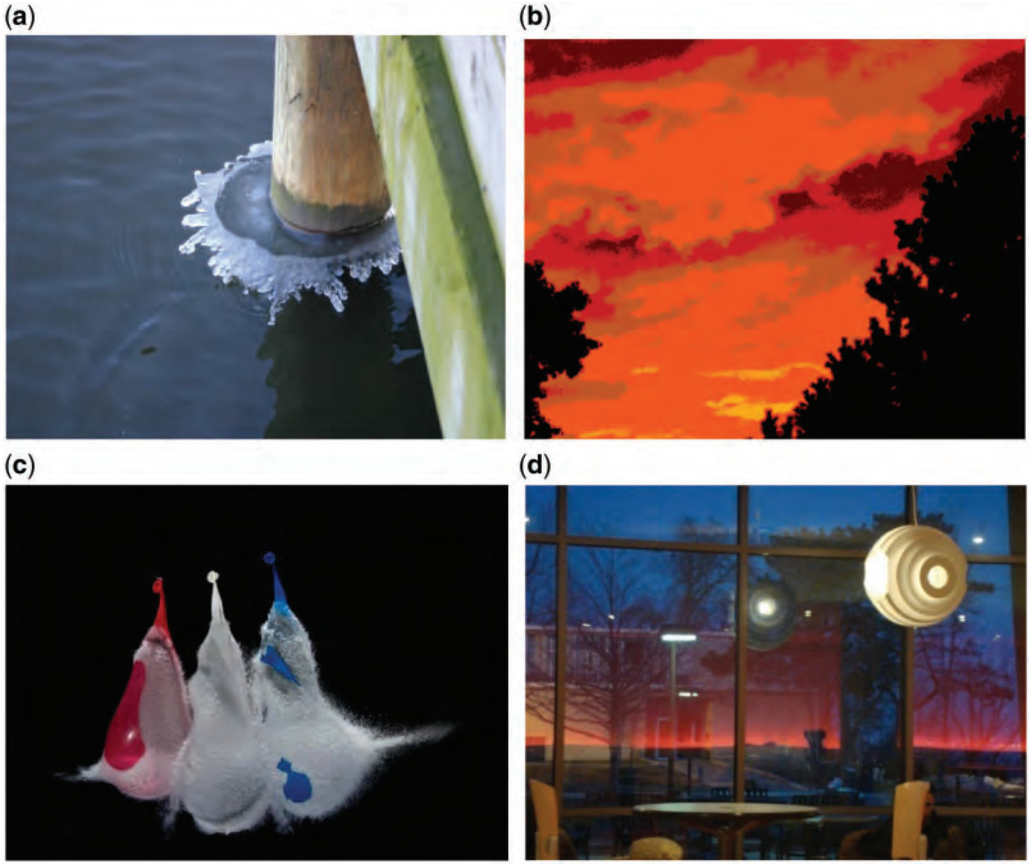
		Not at all (1)	Not really (2)	Somewhat (3)	Mostly (4)	Completely (5)
	Photograph					
1	Originality: Is the photograph of an object (or situation) that has not been used to promote mathematics previously (to your knowledge)?					
2	Creativity: Is the photograph of an image that you wouldn't typically associate with mathematics?					
3	Quality: Does the photograph exhibit the mathematical properties that are being promoted?					
4	Did the photographer adhere to the photograph guidelines described above?					
	Mathematics Problems					
5	Quality: Are the problems clearly stated?					
6	Level: Are the problems appropriate for the intended level?					
7	Problem solving potential: Do the problems promote problem solving (as opposed to rote computations, for example)?					
8	Multi-step: Do the problems require one to use multiple steps to solve?					
9	Accuracy: Are the solutions accurate?					
	Poster					
10	Does the poster include all required elements?					
11	Is the poster visually appealing?					
12	Does the paragraph explain how the photograph connects to the classroom?					
	Overall					
13	Is the project of high quality?					
Maximum points: 65						

Appendix Figure A1. No Parking Sign in NYC (Munakata, 2011). This figure appears in colour in the online version of *Teaching Mathematics and its Applications*.

Appendix Figure C1. This figure appears in colour in the online version of *Teaching Mathematics and its Applications*.



Appendix Figure D1. Some sample contributions to the Physics and Art Photo Exhibition. This figure appears in colour in the online version of *Teaching Mathematics and its Applications*.



Student descriptions of the photographs: (**a**) Ice disk: Water is found in nature in three states: solid, liquid and gas. The fluid states, liquid and gas, have water's polar molecules moving around randomly and freely. This allows water to flow and have waves. As drops of water fall off the ice we can see its energy spreading out in the form of small waves. These waves carry only the energy of the drop and not the actual particles of the drop.The ice seen in this picture differs from the fluid phases. This is due to the fact that as water freezes it forms crystal structures, in which the molecules vibrate but are not free to move. These structures cause ice to be rigid, and hence to be able to have an ice disk form above the water. (**b**) Nikon D5000, AF DX 18-55 mm f/4.5 G, ISO 1250, 1 sec. exposure. This is the accompanying image to the unedited version. The difference is that this one has an increased amount of contrast, as well as an effect known as posterization. In the past, this was used to minimize the number of colour tones which made it more efficient and cost effective for printing large posters. (**c**) The making of this image I used a sound trigger I built on a breadboard. The sound trigger sent an electrical pulse to the flashes to capture the image. I set up the flashes in a dark room and placed the object in the center. So in the time that it took the bullet to reach the object the sound would reach the trigger and fire the flashes. (**d**) ROJO (RED.) The idea of the picture was to capture three parallel scenes in the same picture by the effect of light an objects reflecting on the glass. The picture gives the sensation of unreal places but in reality there are three: inside, outside and in between the glass. This effect is created by outdoors natural light and indoors lighting. It is called ROJO (RED) because when the picture is seeing the vivid colour red is the most perceptible element in the piece.

For more pictures from the first exhibition, we point the readers to the website mentioned in reference 4 (Creative Research Center).