Cultural Education for Art and Design based on Scientific Experiences

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Abstract: A new educational system for students of art and design is proposed, which has been practiced since several years in the course "Introduction to Theory of Arts and Design" at Kobe Design University by the present authors and in the course “Synergetics” at Musashino Art University by the first author. In these courses students have experiences to observe geometrical structures and natural phenomena through workshops and experiments. After these scientific experiences they are encouraged to create arts and designs inspired by these insights. In this paper four topics of workshops, sunflower spirals, diffusion limited aggregation, growth of snow crystal and formation of river structure, are explained along with students’ works. This educational system makes natural phenomena more familiar to students, and let them have an ability of creative activities. At present we have a strong need to construct a sustainable society, and fields of design are expected to contribute to it. Since the nature has attained the sustainability to a considerable degree, this educational system will help students to acquire a certain kind of culture needed for investigating sustainability.

Key words: Scientific Experience, Geometrical Structures, Natural Phenomena, Sustainability

1. Introduction

The first and the second authors have a course "Introduction to theory of arts and design" for graduate students of Kobe Design University (KDU). The third author helps with creating computer programs useful in the course. The first author has a similar course “Synergetics” for undergraduate students of basic design of Musashino Art University. The object of these courses is to let students acquire a certain kind of basic culture for art and design through scientific experiences, including experiments and workshops. The motivation of the present authors for organizing these courses is a belief that the scientific experiences are important for education of art and design, because all of us have grown up while observing natural phenomena, and because we have a strong sensitivity to them unconsciously. This kind of sensitivity is considered to help us in creating good works of art and design. Some of results in an early stage of this project were presented at ISIS Symmetry meeting [1, 2] and printed in a monograph [3].

This educational system is organized further to that shown in Figure. 1, where the terms in frames are concepts and contents of education and those below them are topics of lectures and workshops. In the following sections contents of four topics and students' works are introduced. Expected positive effects of this educational system are noted in the last section.

Basis of Forms

Symmetry and chirality, Golden ratio in nature, Fractal

Space Division / Structure and Function

2D and 3D packing, Quasicrystal, 3D folding

Mechanism of Pattern Formation

Equilibrium form, Form of elastic body, Growth form (DLA, snow crystal)

Pattern Formation of Flows

River branching structure, Random mixing, Patterns by electrophoresis

Sound and Light / Dynamic Structure

Polarized light, Spectrum of image signal, Dynamic structure by gravity

Figure. 1. Educational system for students of art and design based on scientific experiences. Terms in frames are concepts and contents of education and those below them are topics of lectures and workshops.

2. Examples of Topics for Lecture and Workshop

2.1 Simulation of Sunflower Spiral

The sunflower spirals are curves observed in the central part of the sunflower (Figure. 2(a)), These curves are produced through arrangement of small yellow flowers caused by two factors, golden ratio phyllotaxis of branches gathered nearly at the top of the stem and the mutual pressing of small flowers at the tops of branches. In the golden ratio phyllotaxis the successive branches come out to the directions after rotation by 137.5° (=360°/(1+1.618...)) from the preceding branch, as shown in Figure. 2(b). Then, the sunflower spirals can be drawn by the method which is made of the following three processes (see Figure. 2(c)):

(a) (b) (c)

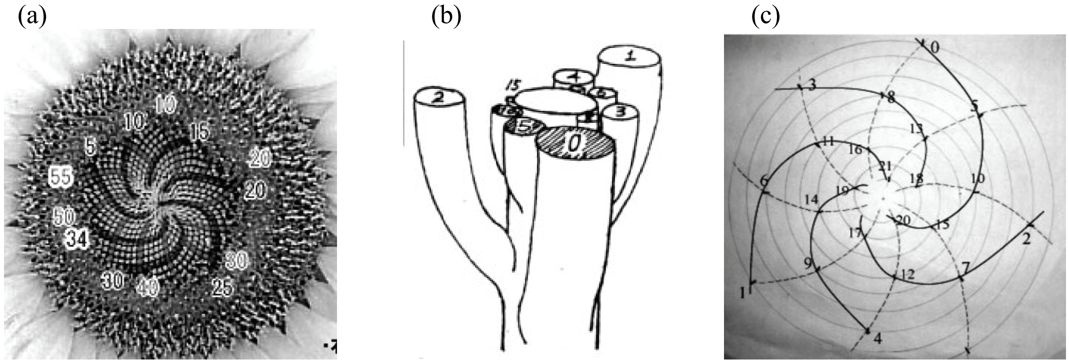


Figure. 2. Drawing of sunflower spirals. (a) Central part of a sunflower with traces of spirals, which are composed of two groups with 55 and 34 spirals (Fibonacci numbers). (b) Mechanism of appearance of spirals, where successive branches (0, 1, 2, 3, ···) come out to directions rotated by 137.5° and hatched branches are located nearby to form a spiral. (c) Simulated sunflower spirals by drawing an Archimedean spiral and putting points on it successively after 137.5° rotation around the center, where numbers are given to points in this order. By connecting nearby points two groups of sunflower spirals appear, five solid curves and eight dashed curves (both of them are Fibonacci numbers).

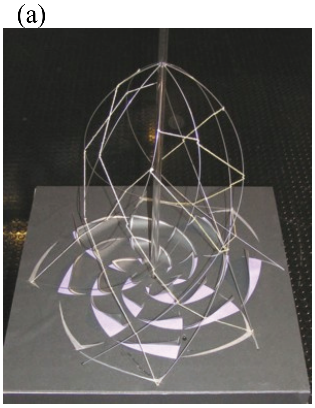
(A) Draw an Archimedean spiral by the use of a pencil, which is connected to a pin fixed on a paperboard with a thread. If the pencil is moved around the pin while the thread is kept tight, the thread is wound around the pencil and the distance of the pencil from the pin decreases. Thus, an Archimedean spiral is drawn.

(B) Put points on this spiral one by one, where each of the successive points rotates around the center of the spiral by 137.5° (a golden division of 360°) from the preceding point.

(C) Connect nearby points to produce two groups of curves.

Figure 2(c) shows resulting sunflower spirals composed of two groups of spirals with five and eight members. These curves are used for art and design according to creative motivation of students. Three examples of students' works are shown in Figure. 3.

(a)



(b)

(c)

Figure. 3 Students works as application of sunflower spirals. (a) 3D structure made from sunflower spirals (H. Wang & S.-R. Kim, 2006), (b) a bag with spiral pattern (T. Inoue, 2010) (c) a garden design (N. Nagahama, 2007).

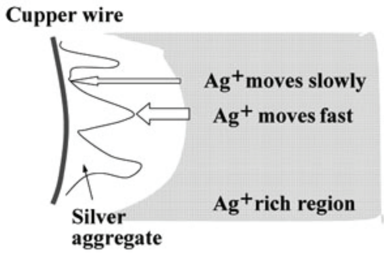
Although the sunflower spirals are drawn according to a fixed rule, the resulting form has no rotational symmetry. This property of sunflower spirals seems to give a special kind of attractiveness. Another example with this kind of attractiveness is the quasicrystal, whose atomic arrangement is determined according to a certain rule but has no translational symmetry. In future these structures will be applied more frequently to creations in various fields of design.

2.2 Growth Forms - Diffusion Limited Aggregation

The term "growth form" indicates a group of forms of objects appearing in nature while growing in sizes. Typical examples of them would be the aggregates produced through diffusion of atoms or molecules (called diffusion-limited aggregation, DLA) and the snow crystals, etc. Processes of production of these objects are influenced much by the physical and chemical conditions of the environment, and have variety of forms. Since these forms are often observed in everyday life, experiments and simulations of these forms attract students' attention. Here, an experiment of DLA and a simulation of snow crystal growth are explained along with students' works inspired by these activities.

In the experiment of DLA a cupper wire is put on a filter paper wet with water solution of silver nitrate ($AgNO_3$), as shown in Figure. 4(a). Then, silver ions come to the cupper wire through diffusion and aggregate to form metal silver on the wire, while cupper ion come out of the wire and diffuse into the water solution, because the ionization tendency of cupper is stronger than that of silver. Here, if there is a roughness on the edge of the metal silver, the speed of diffusion of silver ions from the ion-rich region differs according to the distance to the metal silver, because the diffusion speed is proportional to the gradient of concentration of silver ions. As a result, the tips of protruded edge attract silver ions strongly and the tips grow further. Finally, a lot of branches are developed along the edge. Figures 4(b) and (c) show this process. In high school educations this final result is called “silver tree”.

(a)



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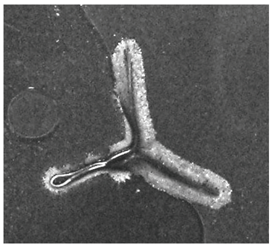


(c)

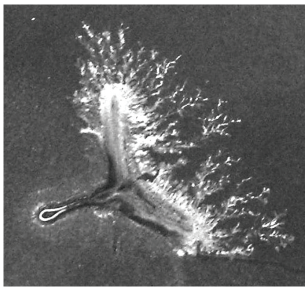
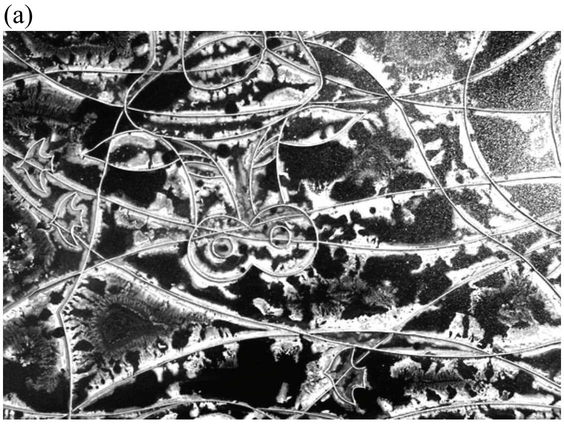


Figure. 4. Mechanism of the diffusion-limited aggregation (silver tree). (a) Difference of diffusion speeds according to the distances to the edge of metal silver, (b) a state before formation of silver tree (10 min. after contact of cupper wire to the water solution of silver nitrate), (c) development of silver tree (250 min. after the contact), which looks like a flying bird.

Figures 5 shows examples of artworks by students and one of the present authors as applications of the diffusion limited aggregation. Figure 5(a) is a group work by four students with size of about 60cm. It took several hours to get silver trees of this size. Figure 5(b) is created by R. Takaki by growing the silver tree on Japanese traditional paper. Figure 5(c) is a rather simple work with size of 8cm, but it is not easy to obtain a silver tree confined neatly within a round boundary.

(a)



(b)

(c)

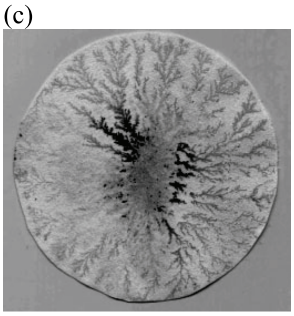


Figure. 5. Artworks by application of silver tree. (a) “Cow”, cupper wires and silver nitrate on a wooden plate (J. Xu, D.-B. Yao, G.-R. Li and M. Liu, 2006), (b) “Buddha’s Lecture”, cupper plate, cupper wires and silver nitrate on Japanese traditional paper (R. Takaki, 2006), (c) a trial of silver tree with cupper wire and silver nitrate on a sheet of filter paper (S. Yasui, 2004).

The surface color of the silver tree is not always silver. In Figure. 5(b) the silver tree is covered partly with stained cupper with green color, while the silver tree of Figure. 5(a) has a relatively pure silver color. That in Figure. 5(c) is partly covered with stained cupper with brown color. At present it is difficult to control this covering.

2.3 Growth Forms - Snow Crystal

Growth of snow crystal is also looked upon as a diffusion-limited aggregation, where the vapor comes to the crystal by diffusion. However, branching structure does not always develop because of the property of water molecules. Nakaya [4] studied growth modes as the effects of temperature and degree of super-saturation of the air, and constructed so-called “Nakaya diagram”, which was later improved by Kobayashi [5], as shown in Figure 6(a).

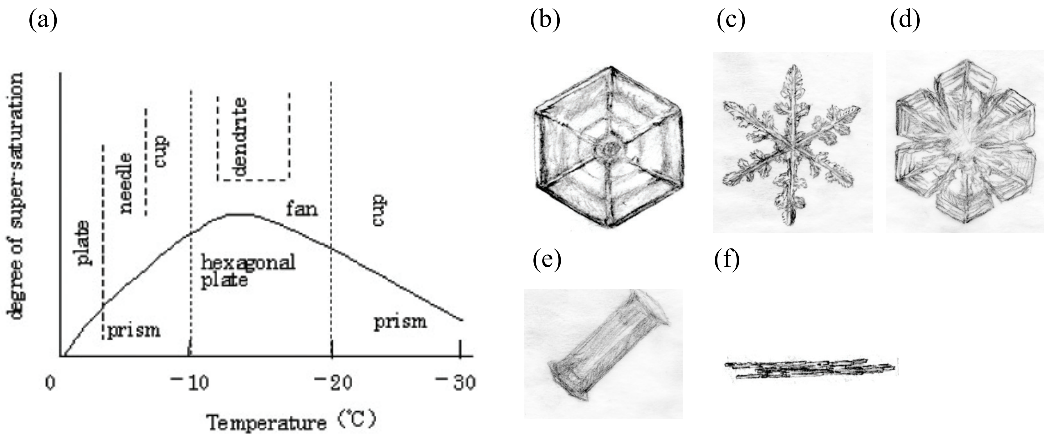


Figure. 6. Variation of growth mode according to the climate conditions. (a) Kobayashi diagram, (b) hexagonal plate, (c) dendrite, (d) fan-type, (e) prism, (f) needle. (sketches by R. Takaki)

According to this diagram, the snow crystal has a form of flat plate with hexagonal symmetry in the temperature ranges, 0 ~ −4°C, −10 ~ −20°C, and column like forms (prism, cup and needle) in the other ranges. In particular, in the range −10 ~ −20°C, the crystal has a form of simple hexagonal plate in lower super-saturation condition (Figure. 6(b)), while in higher super-saturation it acquires a form with tree-like branches called “dendrite” (Figure. 6(c)). In a region between them the crystal takes a fan-like form (Figure. 6(d)).

There is another factor which increases the variety of crystal forms. When a snow crystal falls down, it goes through layers of the atmosphere with various climate conditions, i.e. those of temperature and super-saturation, which appear randomly. Then, while going through those layers the snow crystal grows to outward directions successively with various growth modes according to the Kobayashi diagram, such as a hexagonal plate inside and six dendrite branches outside.

For the workshop in the classroom a simple model made of paper is used to see the mechanism of crystal growth at temperature of about −15°C and with various degree of super-saturation. Elements of crystal and four cards indicating the growth modes are prepared, as shown in Figure.7 (a), (b). The growth modes are limited to the three ones, hexagonal plate, simple and complicated dendrites. The process of workshop is as follows:

(A) An initial stage of crystal growth (left part of Figure 7(b)) is pasted at the center of a paperboard (c).

(B) The four cards are shuffled (to assure the randomness of climate condition) and piled up on the table.

(C) Top card is opened, and elements are pasted to the initial crystal according to the instruction in the card.

(D) Repeat opening the cards and adding elements until the last card is opened.

(a) (b) (c)

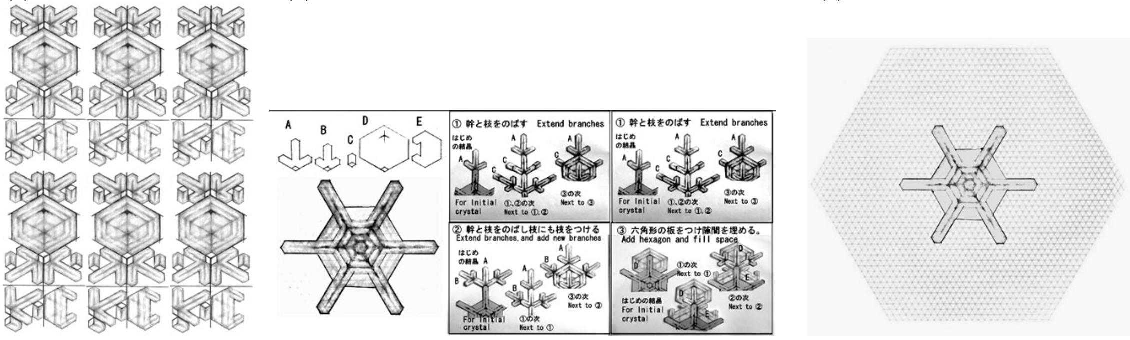


Figure. 7. Paper model for workshop of snow crystal growth. (a) elements of crystal which are cut to small pieces, (b) an initial crystal (left part), which is pasted at the center of the paperboard, and four cards (right part) indicating three growth modes with instructions, (c) paperboard for crystal growth,

Figure 8(a) shows some results of workshop showing the difference of climate conditions. Figures 8(b) and (c) are students' works. They do not necessarily have the realistic forms of snow crystal, but seem to suggest that students were impressed by the mechanism of natural phenomenon and created new forms triggered by the impressions.

(a) (b) (c)

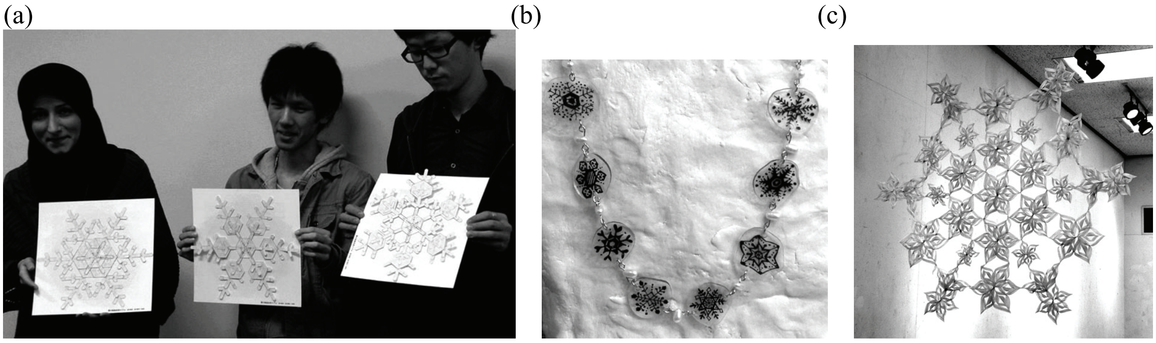


Figure. 8. (a) Results of simulation of snow crystal growth by three groups, (b) pendant with design of snow crystals (A. Niihama, 2011), (c) composition of snow flakes made of thin paper (K. Chang and Y. Ma, 2011)

2.4 Simulation of River Formation

Branching structure of a river is understood to be caused by a random process of mergers of streams. When it rains on the ground with random geography, the water gathers at many hollow spots, which flows further to lower positions, where directions of streams are determined randomly. When two streams meet, they definitely merge to make a larger stream. These two factors, the random direction of stream and the merger after meeting, characterize the forms of river structure.

A natural law was found by Horton [6] which governs number of streams of various stages beginning from origins to a single main stream. Here, we need a rule how to specify the stage of each stream, i.e. number of degree of the stream. Streams from origins have degree-1, and the merger of two degree-1 streams produces a degree-2 stream. In general, merger of two streams with degree-n produce a stream with degree-(n+1). But, merger of two streams with different degrees does not raise the degree, and the stream with higher degree keeps its identity. Figure 9(a) shows a simulated river composed of streams with degree-1~4. Now, count the number of streams of all degrees and plot these data in a semi-logarithmic section paper, then the data are arranged along a line (Figure 9(b)), i.e. the numbers of streams of higher degrees decrease with a constant ratio. This is the Horton's law for stream numbers. Horton proposed other laws for lengths and inclinations of streams and areas of drainage basins, which are not considered here. It is confirmed by computer simulation [7] that the rivers constructed with two factors noted above, the random directions and the merger of two streams, satisfy the Horton's law.

The process of simulation of river formation is as follows:

(A) More than thirty points are fixed preliminary as origins of a river in a pentagonal region (Figure 9(a)). Throw a die to choose one of them randomly.

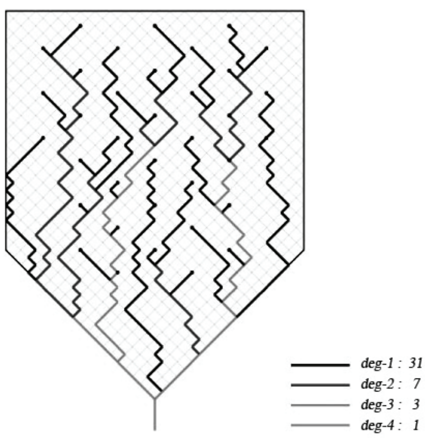
(B) Degree-1 stream is drawn from the chosen origin by throwing the die repeatedly, where the stream goes left-lower for pips 1 ~ 3 and right-lower for pips 4 ~ 6 by one mesh. At the lower boundary of the region the stream is forced to go along this boundary.

(C) When the stream meets another stream, these streams should merge. Then, choose the next origin randomly.

(D) Repeat these processes until streams from all origins are completed.

Figures 9(c)~(e) are students' works created after constructing rivers. Note that these random patterns look quite natural. These patterns can not be produced by humans with free hand.

(a)



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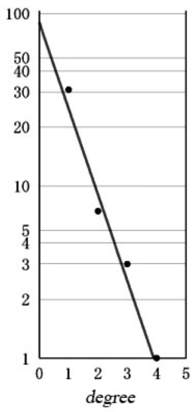
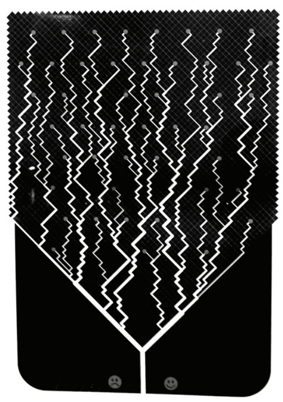
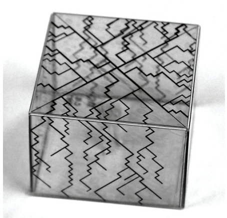


(c)



(d)



(e)

Figure 9. (a) Simulated river structure with 31, 7, 3, 1 streams of degree-1, -2, -3, -4, respectively, (b) Horton's law. (c) Panel with design of river (V.J. Rigoni Kobayashi, 2006), (d) plastic box (Y. Matsuyoshi, 2005), (d) panel of trees with shapes of superposed rivers (N. Endo, 2007). (a), (b): produced by T. Hashimoto, 2005

4. Concluding Remarks

In this paper an educational activities by the present authors are introduced with explanations of four examples of topics. The other topics also include workshops with experiments and simulations of natural phenomena. Some positive effects expected from this educational system are given below.

(1) After workshops students seemed to have a wider aspect of the nature. For example, they had known the dendrite shape of snow crystal (left two ones in Figure 3(a)), but had not known other shapes such as that with small hexagons on the periphery (right one in Figure 3(a)). The relation of crystal shapes with climate conditions seemed to be impressive to them and to have triggered their creative motivation. Knowledge of variety of natural shapes is expected to enrich their design ability.

(2) Some topics treated in this educational system are concerned to scientific knowledge developed in modern age. One example is the sunflower spiral shown in Section 2.1, which is drawn deterministically by a fixed rule but has no rotational symmetry. The quasicrystal discovered about 30 years ago has the similar property. Those kinds of knowledge are attractive to students of art and design, and they enjoy experiments and workshops concerned to these topics. Our sense of beauty for this kind of patterns is not established yet, and its application to design is not popular yet. Another example is the pattern produced by combination of definite natural law and effect of randomness, such as the growth forms (Sections 2.2, 2.3) and the river branching system (Section 2.4). Studies of these phenomena through experiments and workshops will help students in creating designs including realistic natural patterns.

(3) At present the concept of sustainable society is becoming important, and the field of design is expected to contribute to it. The present authors believe that the knowledge of various natural phenomena acquired through experiments and workshops works well in promoting effective activities for it, because the nature has attained the sustainability to a considerable degree. In choosing the topics in the educational system proposed here this hope has been always kept in mind. Whether this hope is actually fulfilled depends on the future activities of students who took this course. The present authors wish that it will be.

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