”Where chaos begins, classical science stops. For as long as the world has had physicists inquiring into the laws of nature, it has suffered a special ignorance about disorder in the atmosphere, in the turbulent sea, in the fluctuation of wildlife populations, in the oscillations of the heart and the brain. The irregular side of nature, the discontinuous and erratic side – these have been puzzles to science, or worse, monstrosities.”

*Chaos. Making a New Science by James Gleick*

# Handicraft and Aesthetic Experience in Teaching Chaos Physics

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# Abstract


- Our aim is to raise awareness of the importance of getting acquainted with chaos physics in the frame of teaching modern physics.

- This time we would like to use handicraft as an aid and come up with some ideas within this topic.

- Apart from raising interest, experiencing the joy of creating something may help students understand and deepen their knowledge of chaos physics.

# Chaos, fractals

**We encounter chaotic phenomena:**

- in our everyday life
- in nature
  - changes in space and time of ocean plankton colonies
  - fluid layers mixing in turbulent sea
  - shooting stars on the sky at summer nights: final phase of chaotic motion of small asteroids
  - in the fluctuation of wildlife population (e.g. the change in number of preys and predators on an island)
  - oscillation of heart and brain activity
  - oscillating chemical reactions
- in art

Chaotic motion is not exceptional but typical (complex behavior of simple systems).

Characteristics of **deterministic chaos**:

- ❑ equations describing the motion are known
- ❑ equations describing the motion are nonlinear
- ❑ the motion is irregular and unpredictable
- ❑ There is order in the phase space: **fractal structure** appears

# Chaotic mixing patterns in the environment

## Fractal structures become visible in physical space

**Oil on the surface of water**

**Fractal sturcture: Cantor filaments**

*Photo: Traian Antonescu*

# Teaching deterministic chaos
## Research experiences

- We examined teaching chaotic phenomena in secondary school Physics classes:
  - ✓ 11-unit module in chaos Physics
  - ✓ extracurricular activity
- Conclusions:

  Chaotic phenomena

  - ➢ can be dealt with at the secondary school
  - ➢ can easily be presented to students
  - ➢ surprise students that even simple systems can behave in a very complex way

# Teaching chaos

We approached the topic from different aspects:

1. Course material, changes of concepts
2. Experiments
3. Use of computer, computer modelling of chaotic systems
4. Aesthetic experience as a motivational tool
5. **Handicraft**

# Handicraft

**During chaotic mixing fractal structures (Cantor filaments) become visible** (in case of other chaotic phenomena the structures only appear in phase space, which is an abstract space) .

**Handicraft activities**

- Painting with marbling technique
  - Painting paper
  - Painting candles
  - Painting eggs
- Dough stretching
  - Decorating marzipan (fractal filament patterns)
  - Making polymer clay jewellery
- Dough mixing:
  - Making unique, fractal filament patterned
    - cakes
    - ice-cream
- Photography

# Applied techniques

## based on chaotic mixing

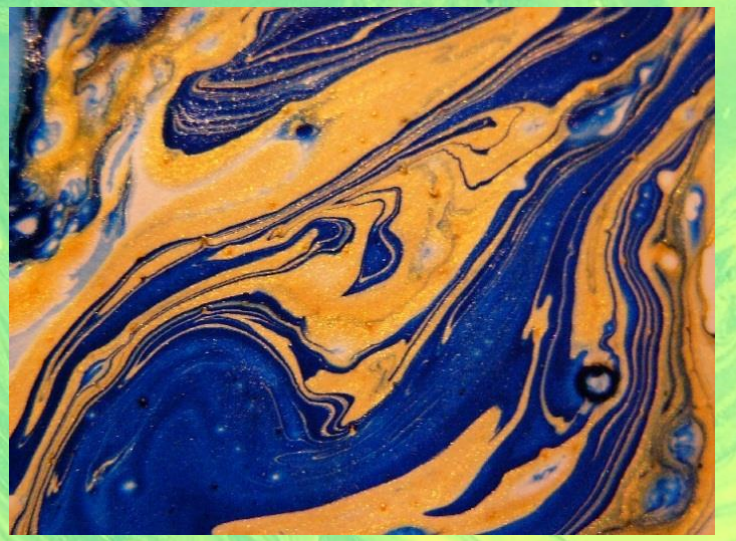
### Marbling

Chaotic mixing in two dimensions:

- we pour a small amount of two or three different paints on the surface of water
- we mix marbling paint
- we place a sheet of paper on the surface

- we flatten the sheet against the surface with quick but definite movements  so that the sheet gets in full contact with  the surface and the paint
- we grab the paper and lift it up carefully
- marvelous fractal structure becomes visible with nice Cantor-filaments

# Painting with marbling techniques: the imprint of chaotic mixing



**Fractal filament patterned sheet:**

- imprint of chaotic mixing
- comprehensible for students

**Paint on the surface of water:**

chaotic mixing or chaotic advection

# Unique wrapping paper

# Painting eggs with marbling technique

Physics class  before Easter

# Painting eggs with marbling technique - steps

- fix a stick inside an egg so that it stays stable
- fully immerse the egg under the water
- pour small amounts of paint (two or three different colors) on the surface of water
- mix them in order to have a beautiful pattern with fractal filaments
- take out  the egg immediately, but very slowly so that  the paint should be evenly distributed on the surface of the egg
- marvelous fractal structure becomes visible with nice filaments
- be careful, do not put down the egg until fully dry

# Drying eggs

# Fractal patterned Easter eggs

# Candles with fractal filaments

# Painting candles with marbling technique - steps

- immerse the white candle in water using tweezers
- pour a small amounts of paint (two or three different colors) on the surface of water
- mix them to have beautiful patterns with fractal filaments
- remove the candle from the water immediately, but very slowly to allow time for the paint to stick to the surface of the candle
- paint should be evenly distributed on the surface of the candle
- marvelous fractal stucture becomes visible with nice filaments
- make sure the candle is fully dried before touching it

# Competitions for students

- Fractal patterned cake, cream or ice-cream

- Polymer clay jewellery

**Photo contest**

Chaotic scattering on Christmas-tree ornaments

The photo contest winner

# Summary

1. We talk about chaos theory, the order appearing in phase space (i.e. fractal structures).
2. We get acquainted with mathematical fractals.
3. We raise students' awareness that fractal structures become visible during chaotic mixing.
4. We observe fractal patterns during mixing (e.g. cream in coffee, syrup in water, ink in water, mixing of paints etc.)
5. During handicraft activities students experience the process how the pattern develops. They enjoy creating works of art.
6. When we return to the topic of chaotic phenomena, their understanding is much deeper.

# Conclusions

- Handicraft activities are suitable tools for raising students' interest in Physics, more specifically in chaotic phenomena.
- Marbling and dough stretching give opportunity to get to know the characteristics of chaos.
- Creating works of art helps to deepen understanding.
- Aesthetic experience in class increases motivation in everyday school life.

Students taking photos of their works of art

**Thank you for your attention.**

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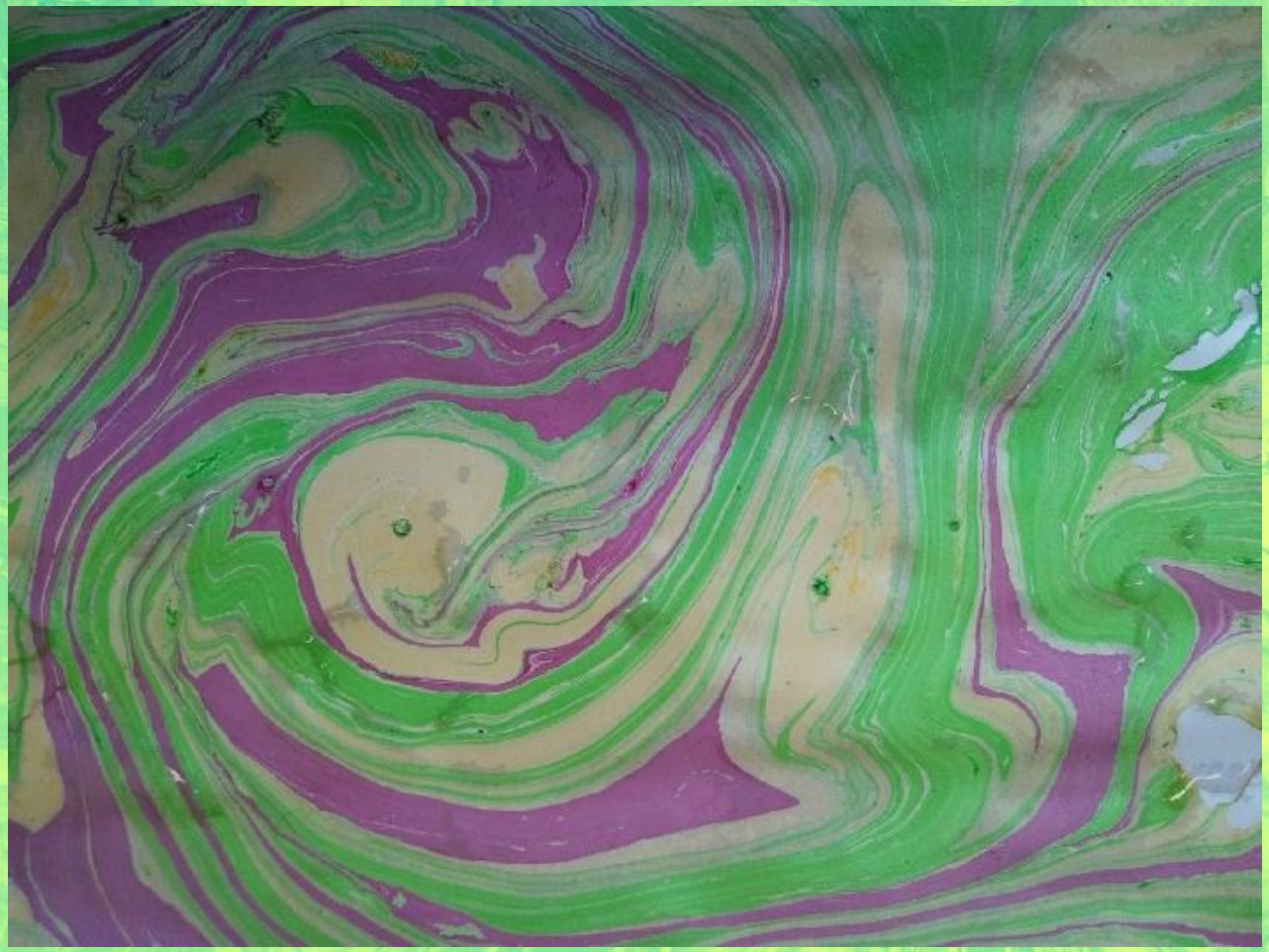
# Unique wrapping paper



# 1. Course material, concepts

**Outlined course material:**

1. Pre-course questionnaires
2. Fractals
3. The concept of chaos
4. Is chaos useful?
5. Iterations with a calculator
6. Examples of chaos in mechanical systems – Experiments 1
7. Examples of chaos in mechanical systems – Experiments 2
8. Examples of chaos in mechanical systems – Computer aided simulations
9. Further examples, summary, review
10. Post-course questionnaires
11. Discussion

**Concepts under investigation:** chaos, predictability, complex and chaotic motion, deterministic systems, reversebility

# 2. Experiments

- Spring pendulum
- Yo-yo
- Double pendulum
- Pendulum with a harmonically oscillating suspension
- Magnetic pendulum

*Magnetic pendulums (Commercially produced and hand-made)*

# 3. Computer aided simulations

We investigated chaotic mechanical systems with the help of computer-aided simulations:

- magnetic pendulum
- double pendulum
- pendulum with a harmonically oscillating suspension
- ball bouncing on a double slope

We graphically represented the characteristics of motion in function of time using simulation software.

We focused on the characteristic features of nonlinear deterministic systems:

- sensitivity to initial conditions (reason: the equation describing the motion is not linear)
- unpredictability

# 4. Art as a motivational tool

- Raising interest has a significant role in teaching Physics: art provides an exciting aid.
- Works of art might raise students' awareness.
- Observing natural phenomena give aesthetic experience.

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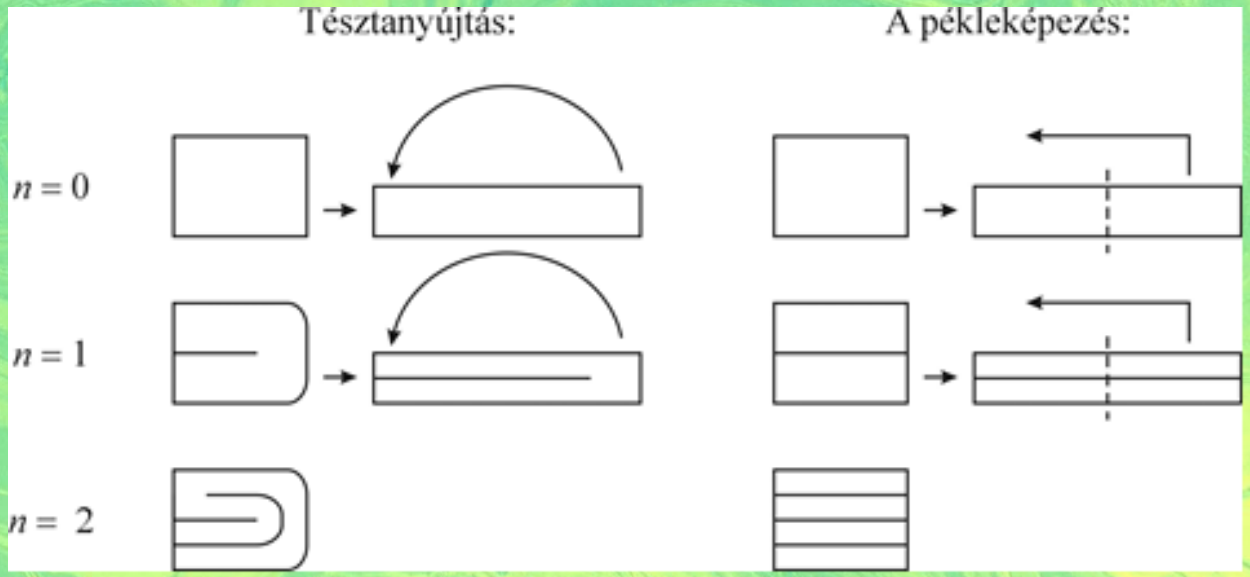
# /Dough stretching/

## chaotic mixing in three dimensions

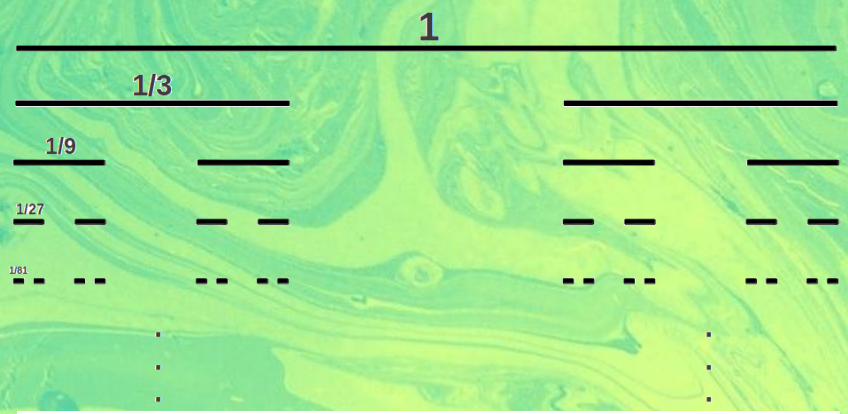



The best mixing can be reached by the algorithm of stretching and folding. It is a chaotic process, called a **baker map**:

- when making puff pastry we first stretch the dough and then fold it (just like our grandmothers)
- we stretch the two-layered dough and fold it again
- we keep repeating the above steps

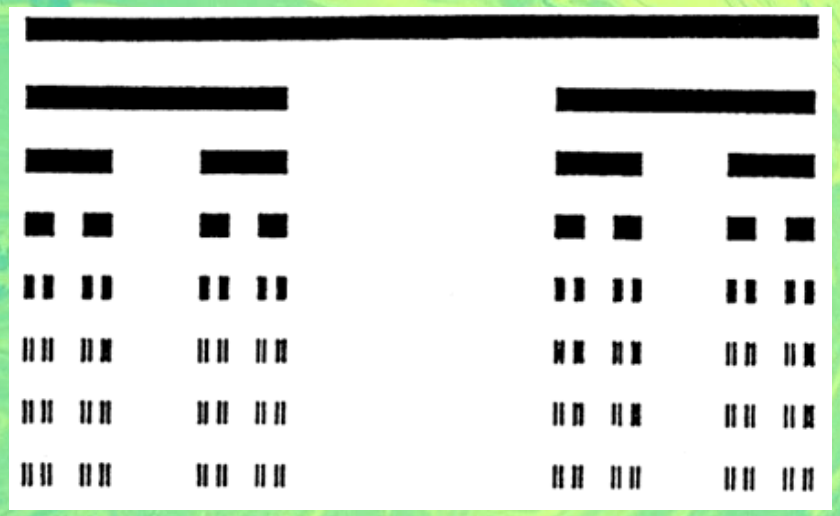
We can use the same algorithm for making fractal-patterned polymer clay jewellery.

# /Mathematical fractals/




**Cantor set**

**0 < D < 1**



**Cantor filaments**

**1 < D < 2**

# Chaotic mixing patterns in the environment

## Fractal structures become visible in physical space

**Oil stain on the surface of water**

**Fractal sturcture: Cantor filaments**

*Photo: Traian Antonescu*