III. FRACTAL APPROACH AND COMPUTER MODELING TO TEACHING PHYSICS, MATHEMATICS AND TECHNICS

In Section 2, we analyzed the peculiarities of the formation of dissipative structures in non-crystalline structures, the different levels of ordering and the transition between them in the flow of energy and information. The uniqueness and beauty of synergetics manifests itself in the integrity of the results obtained and the possibility of their application to radically new areas, in particular, information technologies, teaching of educational sciences. In this section, we will focus our attention on this particular branch of branching out, their bifurcation and stability, synergy and fractality in the teaching of natural sciences. As we shall see in the synergetics there are no void and contradictions, division - the functions and actions are finally functioning and open, creating a symbiosis of knowledge and practical implementation.

The present chapter considered and appraises the fractal approach to teaching physics, mathematics and technics using computer modeling in the environment of the object-oriented programming, Delphi. It manifests the formation of a fractal structure and the corresponding iteration, reflecting the integrity and spontaneity of information perception. The chapter elaborates the iteration of the fractal structure on the example of studying physics sections, “Geometric optics,” and “Wave optics”. Each iteration (section of physics) is characterized by a synergy - adding new iteration provides a qualitative perception of the information. The possibility of using this approach in other sections of physics, and research fields related to physics has been demonstrated.

Innovative teaching of physics and computer modeling of natural phenomena, as well as the application of these methods by teachers, are the focus of special attention in scientific literature (Christian & Esquembre, 2007; Potter & Peck, 1989;
Sladek, Pawera & Valek, 2011). However, special training of future physics teachers on numerical modeling of physical phenomena; bibliographic data in the pedagogical literature, as well as in educational practice are encountered less often. For example, the curriculum of training future teachers of physics in all five Slovakian universities does not contain this subject. Students and future teachers can get acquainted with the problem of computer modeling of physical phenomena while studying special subjects such as “Digital technologies in teaching physics”, “Computer Information Technologies in Physics” (http://www.fpv.umb.sk/katedry/katedra-fyziky/studium/bakalarske-studium/). A similar situation with mastering these methods is observed in other universities.

In the process of teaching physics, attention is focused on a significant amount of material and its unstructured character (Özcan, 2015; Hodson, 2014; De Cock, 2012; Fojtík, 2013), insufficient relationship and correlation with other disciplines (Hestenes, 2010; Huffman, 1997) and practical application (Reif & Heller, 1982). It points to the need for information perception in higher educational establishments, especially in teaching physics at an intuitive level, using visualization means, modern advances in programming – object-oriented programming.

The aim of which the investigation was the implementation of the educational experiment based on the positive impact of the applied measures aimed at creating the optimal object of professional competence of future physics teachers. The study objective was to determine the impact of implementing innovative approaches on the willingness and interest of future physics teachers to independently conduct computer simulations of physical phenomena.

3.1. Investigation methodology: methods used

There is a relationship between the different branches of physics and among its very sections that can be demonstrated using a fractal approach (Mar’yan & Yurkovych, 2015). This means that in teaching one of the sections (subsections), an
algorithm can be determined that is produced and realized in the following sections and, thus, a complex structure is formed while maintaining the integrity of material perception using computer modeling. This approach is tested in teaching electromagnetic phenomena in the sections of physics, “geometrical optics,” and “wave optics.”

A fractal is a branched or dispersed structure, whose dimension is different from that of an integer (Falconer, 2003). There are geometric, algebraic and stochastic fractals (Frame & Mandelbrot, 2002), applied in various fields of physics in modeling of non-linear processes, such as turbulent fluid flow, diffusion processes, plasma, porous materials (Shuster, 1984; Haken, 1985). One of the properties of fractals is self-similarity on spatial and temporal scales, which predetermines the usage of one algorithm in the formation of complex structures with a minimum dissipation of energy (Nicolis & Prigogin, 1989; Haken, 2006; Mar’yan & Yurkovych, 2015; Mar’yan & Yurkovych, 2016). This may be illustrated by the so-called Sierpinsky’s
carpet in Fig. 3.1.1. The Sierpinsky’s carpet is a line that has an infinite length and confines the finite area (see Appendix B).

This line is the self-similar, i.e., composed of three parts that are similar to the entire curve as a whole with the ratio of similarity one to two, and fractal dimension \( d_f = 1.5849 \) (Falconer, 2003) (Fig. 3.1.1).

\[ \text{Fig. 3.1.2. The example of computer simulation for electromagnetic phenomena.} \]

Computer simulation has become a creative means of solving applied scientific and technical problems of physics, but at the same time it is equally important in the educational process, along with cognitive, informational technologies that are powerful (Fig. 3.1.2).
The assimilation of computer simulation opens enormous opportunities for using modern technologies in their scientific and educational activities for the implementation of interdisciplinary connections in computer science, mathematics, physics and other subjects. It involves a detailed analysis of the physical phenomenon or process, the construction of the physical model (abstraction from minor effects, the choice of laws that describe the corresponding processes), the creation of a mathematical model, the implementation of its means of information technology, conducting relevant calculations and analysis of the results. The application of computer modeling, as shown in Fig. 3.1.2, provides for the iteration and "formation" of the model in a loop: 1-physical model, 2-mathematical model, 3-calculation methods, 4-algorithm and model calculation program, 5-testing conduct and model research, 6-comparison of calculation results with experimental data and subsequent refinement of the model. This cycle repeats the necessary number of times, approaching the real object (phenomenon). Consider each of the stages of computer simulation (Fig. 3.1.2). The first stage is the physical model. The physical model for electromagnetic phenomena is a model of electromagnetic waves and environments in which they propagate. The second and third stages are mathematical models and methods of their calculation. Fourth - the use of modern algorithmic programming languages Object Pascal, C++, Java, Ruby. The fifth and sixth stages - the testing and debugging of the program, the calculation and comparison with the optical experiment (Yurkovych, Seben & Mar’yan, 2017).

In the process of teaching physics, attention is focused on a significant amount of material and its unstructured character, insufficient relationship and correlation with other disciplines.

However, internally, there is a relationship between the different branches of physics and among its very sections that can be demonstrated using a fractal approach (Mar’yan & Yurkovych, 2015, Yurkovych, Seben & Mar’yan, 2017). This means that in teaching one of the sections (subsections), an algorithm can be determined that is produced and realized in the following sections and, thus, a
complex structure is formed while maintaining the integrity of material perception using computer modeling. This approach is tested in teaching electromagnetic phenomena in the sections of physics, “geometrical optics,” and “wave optics”. It applies the environment of the visual programming, Delphi - Embarcadero RAD Studio XE8, and the algorithmic programming language, Object Pascal, which is built on the principles of Object-Oriented Programming and the latest information technologies—RAD (rapid application development), VCL (visual component library), DLL (dynamically linked libraries), OLE (object linking and embedding) (Sugden, 2009; Bucknall, 2001; Yurkovych, Seben & Mar’yan, 2017).

3.2. Process and the results of solving the issue: fractal structure.

The first iteration. The laws of reflection and refraction of light (the Law of Snellius). This is analogous to the first iteration of the fractal—the Sierpinsky’s carpet in Fig.3.1.1a. The algorithm contains the features of computer modeling of the light propagation process at the interface of two environments, and is further used for the following phenomena (steps), forming a more complex but internally self-sufficient fractal structure.

In the course of the lecture students consider the basic laws of geometrical optics and types of light reflection: mirror (parallel light rays remain parallel after reflection (smooth even surfaces) and diffuse (parallel rays after reflection are scattered in all directions (rough uneven surfaces) with the immediate transition to computer modeling. The laws of geometric optics: 1) the law of rectilinear propagation of light - in a homogeneous transparent medium light travels rectilinearly; 2) the law of independence of light rays propagation – light rays which are distributed in space do not influence each other at the intersection; 3) the law of reversibility of light rays – if light propagates from point 1 to point 2, then, it propagates according to the same path in the opposite direction from point 2 to point 1; 4) the law of light reflection - the incident ray, the reflected ray and the
perpendicular set in the point of incidence lie in the same plane; wherein the angle of incidence \(\alpha\) equals the angle of reflection \(\beta\): \(\alpha = \beta\).

After consideration of these laws in the environment of visual programming Delphi - Embarcadero RAD Studio XE8, the students create the interface (Fig. 3.2.1): the following components are used (Bucknall, 2001): MainMenu – formation of the main menu (Mirror reflection, Diffusion reflection, Snell’s law, Illustration), Label – labels to describe the panels of entering the output values, Edit – data fields, PaintBox – output of graphic image of mirrored and diffuse reflection). The example of program code in Object Pascal is given in Appendix C.

Students have the opportunity to directly modify the parameters of the optical system (angle of incidence \(\alpha\), refractive index \(n\), the factors of reflectivity and diffuseness), means of visualization of the rays in Delphi environment (colors of the incident and reflected rays, types of lines) and become active self-sufficient participants in conducting computer experiment in Fig 3.2.1. It is important to develop the algorithm of information perception by students on the intuitive level that will be used and developed further in later iterations (lectures) (Yurkovych, Seben & Mar’yan, 2017). It is important, however, that the laws of optics are not perceived separately, not standardized as reports of forced execution and duplication, but they come to life through synergy and principles of object-oriented programming of computer simulation: encapsulation (self-sufficiency), inheritance (creation of a new), polymorphism (distribution in new environments). Students get the opportunity to be self-sufficient, to create a radically new, to perceive different environments (physical environment, programming environment, information environment), which become not passive (as in the traditional approach), but active - complementary, interpenetrating. It also determines the ability of accumulation and spontaneity in other areas of knowledge, including economics, information technology, mathematics, engineering, and others. That is, the tandem "student-teacher" is filled with activity, ability to develop and rich functioning. This is not an over-saturation with inadequate information, namely the spontaneous, self-
organized acquisition and receipt of information objects through the formation of an appropriate fractal structure.

This iteration, this step is essential for the further functioning of the complex structure of the student-teacher and the transition to a new level of perception of information, to the formation of a unique branched structured system.

The new and full-fledged value is also acquired by information technologies of computer modeling: RAD (rapid application development) - creative approach and development, VCL (visual component library) - visualization of the laws of physics with preservation of their information integrity of perception, DLL (dynamically linked libraries) – dynamic perception of information. The change and interpenetration of information environments, OLE (object linking and embedding), is a transition between different environments with a minimum energy dissipation, synergistically (Mar'yan & Szasz, 2000).

The concept of object-oriented programming implies that the basis for managing the implementation of the program is the transmission of messages to objects. Therefore, information objects are defined in conjunction with the messages they must respond to when executing the program. This is the main difference between object-oriented programming from procedural programming, where separate data structures are passed into procedures (functions) as parameters. Thus, object-oriented programming consists of information objects - individual pieces of code that interact with each other through certain interfaces.

This shows the perfect implementation of synergy - the complementarity of information objects. This also manifests itself in the main difference between the approach proposed and adapted in this book to the teaching of natural sciences (see also section 2).
Fig. 3.2.1. The visual interface of modeling the laws of light reflection and refraction in the Delphi environment (Yurkovych, Seben & Mar’yan, 2017).

The second iteration. Total internal light reflection in Fig. 3.2.2. This is analogous to the second iteration of the fractal—the Sierpinski’s carpet in Fig.3.1.1b. It is important to note that the formation of this and subsequent iterations retain the “algorithm” of the fractal structure incorporated for the previous iteration that ensures the integrity, self-sufficiency and localization of perception.
Fig. 3.2.2. The visual interface of computer modeling of the total internal reflection phenomenon (Yurkovych, Seben & Mar’yan, 2017).

It is important to use computer modeling (Gould & Tobochnik, 1988; Yurkovych, Seben & Mar’yan, 2017), which determines the cross-cutting nature and the spontaneity of the material presentation, the features of object-oriented
programming languages developed on the principles of encapsulation, inheritance and polymorphism (Bucknall, 2000; Cantu, 2008). Because of this, each iteration makes use of the properties of the previous one, and, at the same time, it must contain new information (property, method)—in this case, the possibility of directional light propagation.

Tentatively the laws of refraction are formulated as follows: 1) incident ray, refracted ray and the perpendicular at the point of incidence lie in the same plane; 2) the ratio of the sine of the incidence angle $\alpha$ and the sine of the refraction angle $\beta$ is constant for two separated environments:

$$\frac{\sin \alpha}{\sin \beta} = \frac{v_1}{v_2} = n_{21},$$

where $v_1$ is the speed of light in the first environment; $v_2$ - the speed of light in the second environment; $n_{21}$ - the relative index of light refraction in the second environment relative to the first one. Since $n_1 = \frac{c}{v_1}$, $n_2 = \frac{c}{v_2}$, where $c$ - the speed of light in vacuum, then

$$n_{21} = \frac{v_2}{v_1} = \frac{n_2}{n_1}.$$

(The example of the Snell’s law record for students is given in Appendix D).

The law of light refraction allows us to explain an interesting and practically important phenomenon of total internal light reflection. If we increase the angle of incidence $\alpha$, then, reaching the limit values of the angle $\alpha_0$ (let us call it the angle of total internal reflection), angle $\beta = 90^\circ$. At this angle of incidence and bigger angles, the refracted ray cannot penetrate into the second environment but is reflected - the total internal reflection of light occurs.

If $\alpha = \alpha_0$ then $\beta = 90^\circ$ and $\frac{\sin \alpha}{\sin \beta} = \frac{1}{n}$, $\sin 90^\circ = 1$ then $\alpha_0 = \arcsin\frac{1}{n}$ is the marginal angle of the total internal reflection.

The illustration of the refraction laws and total internal reflection in Delphi environment are depicted in Fig. 3.2.2. Students get the opportunity to change the
parameters of the optical environments, to observe the ray propagation in real time under total internal reflection.

**The third iteration.** *Determination of light transmittance of a thin film taking into account multiple reflections and using the methods of approximation in Fig. 3.2.3.* It is analogous to the third iteration in Fig. 3.1.1c.

Students are introduced to the concept of light absorption - the phenomenon of the reduction of light wave energy during its propagation in the substance as a result of conversing wave energy into other forms of energy. In particular, the absorption of light in the substance is described by Bouguer's law:

\[
I = I_0 e^{-\alpha z}, \quad (3.2.1)
\]

where \( I_0 \) and \( I \) the intensity of a flat monochromatic light wave at the input and output of the layer of the absorbing substance with the thickness \( z \), \( \alpha \) is the absorption coefficient depending on wavelength of light, the chemical nature and state of the substance. The transmittance ratio of \( T \) light shows which part of the light flux falling on the object under study passes through it, without being absorbed:

\[
T = \frac{\Phi}{\Phi_0} = \frac{I - I_T}{I_0 - I_T} \cdot 100. \quad (3.2.2)
\]

The optical density of the D substance describes the degree of absorption of monochromatic radiation and is described by the ratio:

\[
D = \log_T \frac{1}{T} = \log_T \frac{I - I_T}{I_0 - I_T} \cdot 100. \quad (3.2.3)
\]
Fig. 3.2.3. Visual interface of two parametric approximation of light transmittance in the Delphi environment (Yurkovych, Seben & Mar’yan, 2017).

According to the Bouguer's law, the transmittance ratio exponentially decreases depending on the thickness of the sample $z$ (layer of the substance):

$$ T = \exp(-az), \quad (3.2.4) $$

and the optical density depends on the thickness of the sample linearly:

$$ D = \alpha \cdot z \cdot \ln e = 0.43 \cdot \alpha \cdot z, \quad (3.2.5) $$
i.e., the optical density of the substance is directly proportional to the thickness of the layer.

To experimentally obtain dependences of transmittance upon the wavelength in the visible region of the spectrum, the students carried out the two-parametric approximation method (Hestenes, 2010). The two-parametric dependence has been considered (Appendix E):

\[ y = ge^{mz}, \quad (3.2.6) \]

Where \( m, g \) variation parameters which are determined in the process of computer modeling (Fig. 3.2.3).

Therefore, arising out of (3.2.6), it is possible to calculate the values of the vibrational parameters \( m, g \), which correspond to the experimental dependencies of transmittance on the thickness of the sample (see formula (3.2.1): \( y = \frac{1}{I}, \quad g = \frac{1}{I_0}, \quad m = \alpha \)). The visual interface of the calculation program in Delphi environment is given in Fig. 3.2.3 (components Button, GroupBox, Edit, Label, Panel, Memo, Chart, and provide them with the necessary properties including the series type with the help of Object Inspector (Yurkovych, Seben & Mar’yan, 2017)). The qualitative difference of this iteration consists in transmission to obtaining the analytical dependence and its graphical visualization. However, there remains the inherent in previous iterations algorithm of structuring teaching material and enhancing students' attention, involving them in the formation of the fractal structure (Mar’yan & Yurkovych, 2015; Scerri, 2016).

**The fourth iteration.** *Modeling of the optical characteristics of the positive and negative lenses in Fig.3.2.4 is analogous to the fourth iteration in Fig.3.1.1d.*

In order to perform the fourth iteration of the fractal structure the students have been familiarized with some methods of determining the focal distances of condensing lenses taking into account the position of the principal planes and the refractive index of the lens material. In optics, a lens is a transparent for light body
limited by two surfaces. A straight line passing through the centers of the spherical surfaces of the lens is called its main optical axis. The distance between the peaks of the surfaces of the lens is its thickness. Lenses, whose thickness is sufficiently small compared with the radii of curvature of their surfaces, are called thin lenses. This condition is not fulfilled for thick lenses.

The lens can be considered as a system of two refracting surfaces. The system preserving the homocentricity of beams and the image turns out to be is strictly geometric similar to the object, is called a perfect optical system. As the theory proves, the images of objects using an ideal optical system can be constructed without a detailed study of the rays inside the system. It is only necessary to know the focal length and the position of the principal planes.

The main planes of perfect optical systems are called conjugate planes, the linear increase of which is equal to $\varepsilon = +1$. The principal planes coincide in a thin lens and their intersection with the optical axis produces the optical center. The main planes of the lens may be located inside the lens and outside of it depending on the shape of the lens. The rays, parallel to the main optical axis, being refracted in the condensing lens, intersect at a point lying on the optical axis and is called the principal focus of the lens. There exists the main front focus $F$ and rear main focus $F'$. Distances from the principal planes to the main foci are called the focal distances. According to the rule of signs for the condensing lens $f<0$, $f'>0$, for the disperse one $f>0$, $f'<0$. The optical power of a thick lens can be calculated by the formula:

$$\Phi = \frac{1}{f'} = (n - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) + \frac{d(n - 1)^2}{n \cdot R_1 R_2},$$

where $f'$ is the back focal distance of the lens, $R_1$ and $R_2$ are the radii of the refractive surfaces curvature, $n$ is the refractive index of the lens material, $d$ is the thickness of the lens. In the process of using computer modeling (Gould & Tobochnik, 1988) there exists a significant influence of graphical tools for data visualization (building
various types of graphs for a single analytical dependences, that is, one and the same analytical dependence is observed by students at different visual foci) in Fig. 3.2.4.

![Image of optical properties of a thick lens](image_url)

**Fig. 3.2.4. The visual interface of modeling optical parameters (optical power and focal distance) of a thick lens (Yurkovych, Seben & Mar’yan, 2017).**

**The fifth iteration.** Practical application of the given physical phenomena in Fig. 3.2.5.

It should be noted that the fractal structure has a fractional dimension, completely filling in the corresponding space (Mar’yan & Yurkovych, 2015). The practical application itself is analogous to the fifth iteration in Fig. 3.1.1 and reproduces the integrity and development of the section of physics, “geometric optics.” (Mar’yan, Kikineshy & Mishak, 1993; Mar’yan, Kurik, Kikineshy, Watson & Szasz, 1999; Young & Freedman, 2003 ).
To create the interface of the program in Fig. 3.2.5, students were asked to use the object Image in Delphi environment (properties of Picture and Stretch of the object Image (Yurkovych, Seben & Mar’yan, 2017)).

The students got acquainted with the technical product — optical fiber consisting of an optical fiber waveguide, protective coatings and marking colored membrane. The optical fiber waveguide is the physical medium of transporting an optical signal and consists of a core and membrane having different values of refractive indices. It is emphasized that owing to the phenomenon of total internal reflection there is the possibility to transport optical signals (light) generated by the source. The types of optical fiber have been considered in Fig. 3.2.5: single mode fiber; multimode fiber; gradient fiber; a polarization-stable fiber; photonic crystal fiber.

The next part of the practical application is the process of accommodation light rays by the lenses in Fig.3.2.5. The eye undergoes the process of accommodation not so much by the change of curvature of the eye-lens, but rather by the influence on the shape of the eyeball by external muscles that surround it. Let us provide some simplified explanation for the students to understand what is being described. Comparing the structure of the eye with the device of the camera has become a common matter in ophthalmology.

If we draw the analogy between the structure of the eye and the device camera, the role of the lens in the eye is performed by the transparent elastic formation having the shape of a biconcave lens, i.e. the eye-lens. It is emphasized that the light rays reflected from an object enter the eye and, passing through the lens, are focused on the retina. The retina is an analogue of the photosensitive film in the camera – there is a thin membrane that lines the inner surface of the eye in Fig. 3.2.5.

Each iteration (section of physics) is characterized by a synergy - adding new iteration provides a qualitative perception of the information (without a mechanical outside introduction of the division according to themes), the formation of the
integrity in which the student becomes an active participant (Haken, 2006; Mar’yan & Yurkovych, 2015). This synergy creates a unique fractal structure, capable of development and functioning (Mar’yan & Yurkovych, 2016).

The iteration discussed above can be complemented and developed, in particular by involvement of learning using the testing tools (Hodson, 2014), the exchange of information using the Internet (Mieke De Cock, 2012), that is, the process generates and allows an infinite number of steps, which is essential for fractal structures (Frame & Mandelbrot, 2002).

Fig. 3.2.5. Practical use of the phenomenon of total internal reflection in fiber-optic communication lines and optical lenses.

Based on the presented approach of the joint synergistic usage of lectures on physics and computer modeling, the fractal structure (table 3.2.1) is formed on an
intuitive level (Sherin, 2006). Functioning of this structure is manifested in the transition to the presence of students' self-sufficiency, involving the use of creative approach and the desire to apply the obtained information in radically new areas (Young & Freedman, 2003). For example, the phenomenon of total internal reflection along with the classical perception of physics as a process of dissemination of information (Informatics), preparing a hamburger (cooking), the Belousov-Zhabotinsky reaction with the formation of dissipative structures (chemistry), dancing rhythms (music).

Table 3.2.1. The formation of the fractal structure of information perception.

<table>
<thead>
<tr>
<th>Steps</th>
<th>Levels of information perception</th>
</tr>
</thead>
<tbody>
<tr>
<td>The first step</td>
<td>Physics</td>
</tr>
<tr>
<td>The second step</td>
<td>Physics and computer modeling</td>
</tr>
<tr>
<td>The third step</td>
<td>The intuitive perception of information by students and the formation of the fractal structure</td>
</tr>
<tr>
<td>The fourth step</td>
<td>The hyper sensibility and distribution of fractal structure in the integrated environment</td>
</tr>
<tr>
<td>The five step</td>
<td>The formation of an integrated fractal structure</td>
</tr>
</tbody>
</table>

The resulting fractal structure is qualitatively manifested in the table 3.2.2 (Yurkovych, Seben & Mar’yan, 2017).
<table>
<thead>
<tr>
<th>Iterations</th>
<th>Objects</th>
</tr>
</thead>
<tbody>
<tr>
<td>The first iteration</td>
<td>Computer modeling the laws of light reflection and refraction</td>
</tr>
<tr>
<td>The second iteration</td>
<td>Computer modeling the laws of light reflection and</td>
</tr>
<tr>
<td></td>
<td>the total internal reflection phenomenon = { Synergy of integration in the Delphi environment }</td>
</tr>
<tr>
<td>The third iteration</td>
<td>Computer modeling the laws of light reflection, the total internal reflection phenomenon and two parametric approximation of light transmittance = { Synergy of integration in the Delphi environment }</td>
</tr>
<tr>
<td>The fourth iteration</td>
<td>Computer modeling the laws of light reflection, the total internal reflection phenomenon, two parametric approximation of light transmittance and the modeling optical parameters of a thick lens = {Synergy of integration in the Delphi environment }</td>
</tr>
<tr>
<td>The fifth iteration</td>
<td>Computer modeling the laws of light reflection, the total internal reflection phenomenon, two parametric approximation of light transmittance, the modeling optical parameters of a thick lens and practical use of the phenomenon of total internal reflection in fiber-optic communication lines and optical lenses ={Synergy of integration in the Delphi environment}</td>
</tr>
</tbody>
</table>
3.3. Results of research: discussion and conclusions

Thus, a fractal structure in teaching one of the sections of physics, “geometrical optics,” is formed (it can be easily spread to other branches of physics). The advantages of this approach are obvious: the corresponding physics section is perceived as a single unit without the mechanical separation into its component parts; and the possibility of forming branched structures according to a single algorithm that can be extended to other branches of physics, while maintaining the integrity (fractality) at the level of several sections (Breslyn & Mcginnis, 2012; Kuo, Hull, Gupta & Elby, 2013).

Fig. 3.3.1. An example of one of the branches of the fractal structure.

The given approach is also used in the formation of a fractal structure, which is implemented, in particular, in the transition from geometrical to wave optics. Moreover, the iterations analyzed above, iterations 1–5 in Figs. 3.2.1–3.2.5, are
considered as the first iteration of a new fractal structure formation (an example of one of the branches of a fractal structure see Figs. 3.3.1, 3.3.2). It should be noted that unlike the classical approach, which is based on the assimilation of a certain amount of material (Özcan, 2015; Hodson, 2014), the fractal connections reflect the internal structure of the sections (Mar’yan & Yurkovych, 2015; Mar’yan & Yurkovych, 2016) that are assigned spontaneously. In computer modeling, along with the use of the algorithmic programming language, Object Pascal, other object-oriented languages such as C++, Java, and Ruby, can be used.

The offered fractal approach of teaching physics has been probated in the Uzhgorod National University (Uzhgorod, Ukraine), the Faculty of Physics, Department of solid-state electronics & information security and University of Presov (Presov, Slovakia), the Faculty of Humanities & Natural Sciences, Department of Physics, Mathematics & Techniques for students in the third course—the future physics teachers for the physics sections “Geometric optics”, and “Wave optics”.

During these classes, the activation of students, and in-depth perception of the material have been noted. In our opinion, the adoption and usage of the methodological approach of modeling physical phenomena and processes by future teachers of physics is very useful (Windschitl, 2004). It creates space for the expansion and implementation of the key competencies in the field of targeted and effective use of information and communications technology in school physics experiments (Luft, 2001; Lotter, Harwood & Bonner, 2007; Schwartz & Lederman, 2008).

So, the fractal approach to teaching physics using computer modeling in object-oriented programming, Delphi, has been substantiated (Fig. 3.3.3). The formation of a fractal structure has been established and the iteration has been determined, which reflect the integrity and spontaneity of presenting information. The lectures for students of Prešov University in Slovakia and Uzhgorod National
University in Ukraine with the use of a fractal approach in teaching physics sections “Geometric optics”, “Wave optics”, and computer modeling have been conducted.

Presents synergetics and fractality approach in this book identify and attract to use the modern level of the latest information technologies: information exchange in the Internet network, development of mobile telecommunications and related technologies, level of abstraction and synergy of object-oriented algorithmic programming languages, formation of the self-sufficient systems - smart home, intelligent car, smart phone (Chen & Lee, 2009). They provide an opportunity to implement a reasonable lecture, a reasonable audience, a sensible conference with the direct embodiment of ideas and development (Figs. 3.3.2-3.3.3).
Fig. 3.3.3. Formation of the dissipative fractal structure of the teaching physics.
At the present stage in the process of mastering the sciences and technologies in the higher education establishments, universities considerable attention is mainly focused on a significant amount of material and its unstructured nature, insufficient interconnection and correlation with other disciplines and their practical application (Balanov & Janson, 2009). This indicates to the need for the presentation and perception of information on an intuitive level, using visualization tools, modern advances in information technology, especially computer modeling and object-oriented programming (Fig. 3.3.4). There is a relationship between the different branches of the education, science, technology and their very sections that can be

Fig.3.3.4. Synergetic of the fractal structure (\((dS)_e\) is an entropy flux which exists due to the energy and information exchange with the environment and \((dS)_i\) is an entropy production inside the system).
demonstrated using a fractal approach. This means that in teaching one of the sections (subsections), an algorithm can be determined that is produced and realized in the following sections and, thus, a complex structure is formed while maintaining the integrity of material perception using computer modeling. It is important to note that the formation of this and subsequent iterations retain the “algorithm” of the fractal structure incorporated for the previous iteration that ensures the self-sufficiency and localization of perception. Use is essential of the computer modeling, which determines the cross-cutting nature and the spontaneity of the material presentation, the features of object-oriented programming languages developed on the principles of encapsulation, inheritance and polymorphism. Because of this, each iteration makes use of the properties of the previous one, and, at the same time, it must contain new information (property, method).

The iterations of the fractal structure on the example of studying physics sections, “Geometric optics” and “Wave optic” elaborated. Each iteration (section of physics) is characterized by a synergy - adding new iteration provides a qualitative perception of the new information. The possibility of using this approach in other sections of physics, and research fields related to physics has been demonstrated. It manifests the formation of a fractal structure and the corresponding iterations, reflecting the integrity and spontaneity of information perception. Based on the proposed synergistic approach to the use of subject areas of knowledge and computer modeling, the fractal structure is formed on an intuitive level. The functioning of this structure manifests itself in a qualitative transition to self-sufficiency of students, which involves the use of a creative approach and the desire to apply the received information in radically new fields.

This section is adapted for the general public: scientists, teaching in high schools, teachers.