Małgorzata MAKIEWICZ[1]

MATHEMATICAL COGNITION IN METAPHORS EXPRESSED THROUGH PHOTOGRAPHY

MATEMATYCZNE POZNANIE POPRZEZ METAFORY WYRAŻONE FOTOGRAFIĄ

Abstract: The paper signals the foundations of the new method of teaching mathematics that is currently emerging from the concept of human cognition and the constructivist paradigm. The presented examples of the hermeneutic research conducted for 17 years are concerned with an analysis of the formulated mathematical problems in the language of photographic metaphors. Thoughts expressed through the photographic image and text consisting of the caption and the description (*dual coding*) reveal the structure of cognitive networks of authors of photographs, which has a special significance in creation of the new didactics that will fulfil the needs of the contemporary photosociety. Mathematical photoeducation free transition between art and mathematics lies on the student's artistic sensitivity and on enlivening the student's cognitive expression in a space distant from the classroom (at a lake, in the playground, on the skating ring or during a field excursion to a mineral museum). It utilizes the student's natural interest in observable natural phenomena and in man-made objects. This kind of creativity, which relies on independent uncovering or constructing of knowledge with the help of a photographic camera, opens the gates to an entirely new space of mathematical didactics, as it brings to students' awareness specific ways of association leading to accomplishment cognitive processes in relation to abstract mathematical objects.

Keywords: teaching mathematics, mathematical culture, cognitive photography, mathematical photoeducation, student's scientific creativity, area-specific and creative abilities in mathematics

Introduction

The objective of this article is to signal the foundations of the new method of teaching mathematics that is currently emerging from the concept of human cognition and the constructivist paradigm. Mathematical photoeducation relies on the student's artistic sensitivity and on enlivening the student's cognitive expression in a space distant from the classroom. It enables free transition between art and mathematics, utilizes the student's natural interest in observable natural phenomena and in man-made objects, as well as enables formulation of mathematical problems in the language of photographic metaphors, which outline the road travelled by photographers on their way to uncover the essence of objects (notions) and the correctness of theses. The structure of mathematical cognitive

[1] Institute of Mathematics, Szczecin University, ul. Wielkopolska 15, 70-451 Szczecin, Poland, phone/fax +48 91 444 12 67, email: mmakiewicz@gmail.com

networks is revealed through dual coding analysis [1] of thoughts expressed by means of a photographic image and a text consisting of a title and a description. This kind of creativity, which relies on independent uncovering or constructing of knowledge with a photographic camera, opens an entirely new space of mathematical didactics.

The need to reconstruct the traditional methods of teaching mathematics

The restoration of the mandatory school of secondary education leaving exam in mathematics in Poland in year 2010 created new challenges for both teachers and students. As demonstrated by the exam result analysis presented by The Central Examination Commission, it is difficult to speak of a nationwide success. In year 2012, the failure rate of the school of secondary education leaving exam in mathematics was 15%, which was the highest of all exam subjects. Results of the PISA analysis conducted every three years by The Organization for Economic Cooperation and Development reveal a steady, even though a very slight improvement in results obtained by Polish 15-year olds within the scope of reading comprehension and interpretation of texts on one hand, while signal alarming deficiency in application of knowledge and in solving non-algorithmic mathematical problems. It is not uncommon for Polish students to attend private tutoring in mathematics, which finds its confirmation in results of comparative studies conducted in all parts of the world by Mark Bray. As a matter of fact, in India, for example, 98.9% of students have a private math tutor in the state of Kreala and 73% in the state of Uttar Prades, where mathematics is not one of the mandatory (exam) subjects [2].

The situation in which on one hand there is a crisis in teaching mathematics and on the other a priority to educate technical personnel and to secure the foundations of mathematical education for future physicians, artists, economists and engineers, creates a certain conflict. The society at large appears to appreciate the significance of teaching mathematical reasoning, but on the other hand attempts are being made by means of legal regulations to limit the understanding of mathematics only to certain concepts, theorems and to calculations and solution of algorithmic problems. The general reflection over the mathematical nature of the universe and the applicability of mathematics is treated with neglect. Also neglected is the mathematical culture, which, apart from general calculation skills, includes understanding of the continuous transition in individual disciplines of mathematics from mathematics as the science and mathematics as the subject, the use of mathematical language, the ability to select the correct method to solve problems, the ability to prove, introduce concepts, imagination, creativity, as well as the ability to perceive beauty [3]. The tool for developing the mathematical culture of the student and for building the student's mathematical maturity may be photography, which since year 1931, thanks to August Sander, is considered as one of the high arts [4].

The application of photography as a cognitive tool within the area of school didactics enables the teaching process to be redirected anew by indicating the avenues of search from perception of art [5] to independent artistic expression, which results in mathematical uncovering of concepts, dependencies, and even discoveries. Creativity comes to life only under favourable didactic conditions. As dully observed by E.P. Torrance, all children have creative abilities, but their development may be impeded by incorrectly designed school education. The incubation model of development of creative attitudes and abilities in students [6] refers to discoveries of subjective nature and local creativity at school. Let's limit the discussion to the two basic levels of creativity: fluid (consisting of basic cognitive, emotional and motivational processes) and crystallized (accomplished by pursuing the goal, solving a problem while understanding its structure, significance and context) [7]. However, as it may be noticed, creative at the basic levels is treated by C. Rogers et al [8] as a condition for achieving higher levels of creativity.

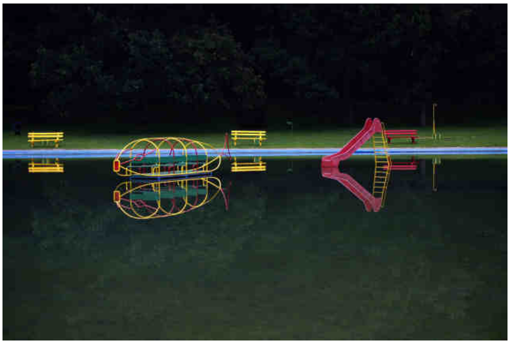
Research as the basis for concepts of new educational activities

Undertaking research into mathematical cognition by means of photography was related to my personal fascination with mathematical photoeducation, which I have been pursuing for 17 years. The very first ideas came to me during the ten years of my work as a teacher of mathematics, an instructor of a photographic workshop, and an organizer of internal photographic competitions at a school of secondary education. I gained my next research experience at The Laboratory of Didactics of Mathematics of The University of Szczecin. The research material, fragments of which are presented here, originate from the documentation of the second and the third edition of The National Photographic Competition *Mathematics in Photographic Lens*. (An annual competition organized by The Laboratory of Didactics of Mathematics of The University of Szczecin since year 2010 under the patronage of The Rector of The University of Szczecin, The President of The City of Szczecin and The Provincial Governor of the West Pomerania province www.us.szc.pl/foto_matematyka).

I was inspired to undertake hermeneutic research conducted by means of analysis of documents (titles and description of photographs) and of analysis of creations (*ie* photographs) by systematically collected data revealing the original approach to the subject matter, high fluency, flexibility and metaphoric of authors' thinking, as well as certain errors related to cognition, imagining and naming of presented objects [9]. In my interpretation of visual materials I followed the instructions of Gillian Rose as regards concentration on a selected area related to the creative process [10]. Because of my interest in the cognitive network of mathematical concepts, I focused my attention on the social context and the author's aspect of the photograph [11]. The applied hermeneutics of suspicion [12] enabled provocation of directed activity and opened an inductive way of creating the theory for the researcher. In the following three editions of The National Photographic Competition I decided not to ask specific questions such as: What is a number? How does parallelism look like? What does a number constitute? How do you picture infinity? [13]. As suggested by Sarah Phink [14], I asked competitors provide their author's comment about their photograph. I focused in my analysis on the entire text of descriptions, as well as on their individual parts [15], as well as accompanying statements, for example interviews with winners during the official conclusion of the competition. As a result, by means of a hermeneutic analysis of the research material I was able to better understand the context of creation of the image and the subjective attitude and intentions of the author. The focus of my analysis was both the visual material and the social context revealed by the title and the description. The objective of the research was to get closer to the correct reconstruction of the cognitive models used by authors and to uncover their own cognitive maps that may or may not be registered in their conscious mind. The titles and the descriptions of photographs presented here pointed towards the way of understanding and the correct interpretation [16]. Such a linguistic message, first and foremost, fulfils the function of anchoring the meaning, as in the case of mathematics images may be interpreted in a divergent way.

Examples of metaphors of mathematical objects expressed through photography

Metaphors may function as perfect cognitive links between the language, the thought and the reality [17], uncover the point of view or the perspective in the search for analogies and differences between two domains [18] and evoke relevant ideas, projecting a brighter light on and ensuring a better understanding of specific phenomena [19]. Therefore, photographs, along with comments, are inscribed in the realistic strategies of teaching mathematics and may be used as examples based on which didactic scenarios for introducing new teaching content, drills, reflection and review may be developed.



Phot. 1. Symmetry (photo by Marta Mazur)

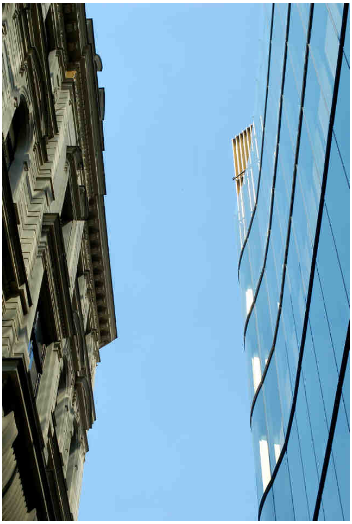
Mirror reflection symmetry, one of the simplest isometries, enchants with its harmony and consistency. Intuitive perception of this conversion is naturally connected with the reflection that may be observed in the mirror or on the surface of the lake.

Phot. 2. Symmetrical reality (photo by Anna Cichos)

Children like to experiment. Raising a leg makes the reflection also raise a leg, the same way as smiling makes the reflection respond with a smile. At the same time, distances, position correlation, and dimensions remain the same. The photograph submitted by Anna Cichos inspires reflection by the captivating effect of the two different images (the reflected image and the reflection). Here the author of the photograph presents *a symmetrical reflection of the figure of Emilia in a rain puddle, whose surface forms a large and effective mirror.*

Phot. 3. Pancake ice (photo by Olgierd Różycki)

A traditional capture of symmetry through the prism of aesthetics and order is not comprehensive enough from the point of view of physicists, crystallographers or naturologists, who prefer to resort to both mirror reflection symmetry and charge, as well as temporal symmetry. A unique photograph of ice formation on the Baltic Sea. The phenomena of water forming regular patterns when freezing relies on local and global symmetry. This transformation, which refers to the congruence of figures and spatial automorphisms has been already discussed by Hermann von Helmholz [20]. Many objects may be defined quite well by means of groups of symmetry.



Phot. 4. The temporal axis of symmetry (photo by Katarzyna Kalkowska)

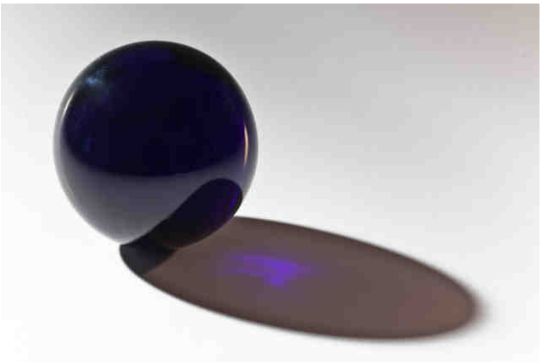
This seemingly distant metaphor of symmetry offers an insight into the state of author's emotions and her intellectual distancing from superficial use of scientific terminology. Such a subtle sense of humour is one of the special premises of creative ingenuity, as it accelerates the flow of thoughts, uncovers hidden similarities and differences, and reinforces the clarity of a message [21]. This is also the case here. An attempt to find an analogy to axial symmetry, *ie* symmetry around an axis, proves to be unsuccessful. This is an invitation (encoded in the title) to depart from the area of mathematics and to take a broader look at symmetry through architecture, time and structure of matter. Not only as spatial isometries, but, more importantly, as the harmony of the universe.

Phot. 5. The Pythagorean theorem (photo by Joanna Taras)

This photograph is a perfect illustration of the essence of the converse of the Pythagorean Theorem: *whenever in a triangle the sum of the squares of two short sides equals the square of the long side, the triangle is a right triangle*. The vertical and horizontal shadows visible in the photograph offer an easy method of verifying whether or not the wall of this structure was erected correctly, *ie* whether or not it maintains the correct perpendicularity. Such a reality-based formulation of the problem differs from the typical wording of "*Find the length of a leg of a right triangle …*" or "*Apply the theorem to …*" and using this photograph during math lessons may be an opportunity to inspire the natural curiosity of the student in the usefulness of mathematics.

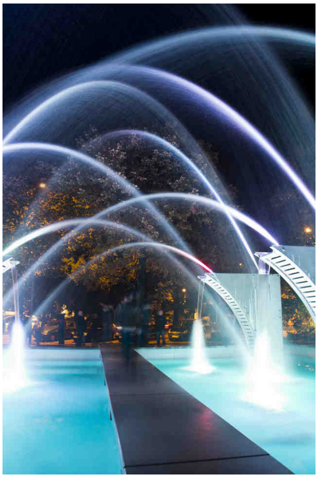
Phot. 6. The sinusoid (photo by Karolina Zwierzchowska)

The ability to notice mathematical regularities in the surrounding world and to comprehend with an open mind the continuous transition occurring in the various mathematical disciplines between mathematics as a science and mathematics as a teaching subject is one of the manifestations of the mathematical culture [3]. Here the author of the photograph, intrigued by the characteristics of the shape of the break in the ice, took a photograph following the principles of Earth Art. - *This photograph was taken in Ińsko, just before enthusiasts of ice swimming took a plunge. The break in the ice resembles the sinusoid, which is the graph of the sine function y = sin(x).*



Phot. 7. The elliptical shadow of the sphere (photo by Daniel Wójcik)

An observation of the changing position of the sphere's shadow in relation to the moving source of light leads to interesting conclusions [22]. As the source of light approaches the projection plane, the shadow becomes elongated. However, the sphere is always touching its shadow (the ellipse) exactly in the focus. A local and a subjective discovery of this focal property of the second degree curve.



Phot. 8. Surrounded by square functions (photo by Michał Cenzartowicz)

The trajectory for projectile motion is the parabola, whose arms are pointed downwards. Water particles in one of the fountains of the City of Szczecin offer an excellent illustration of this characteristic curve in the evening. The intention of the author of the photograph was *to demonstrate how mathematics manifests itself (inverse square function) in our immediate surroundings.*

Phot. 9. Frost covered spider spiral (photo by Ewa Skrzypek)

This photograph was submitted to the competition with the following comment of the author: *Only now do I realize that the spider spins its web in spiral pattern. And what a special spiral it is, indeed.* The comment indicates the subjective discovery defined in the literature as „mini-c" creativity [8, p. 179]. This discovery happened one day in November when the frost covered spider webs in the meadows. The author's enthusiasm and sense of awe were inspired by the harmony of the so-called marvellous or geometric spiral described by the following equation: $r(\alpha) = \mathrm{a} \cdot e^{k \cdot \alpha}$, with e being the base of natural logarithm, $\alpha \in R$, and a and k being positive real constants, describing a curve with a constant angle at which it is intersected by its radiuses.

Phot. 10. *Helix pomatia*. Mathematics as nature's architecture (photo by Cezary Hendryk)

This photographic juxtaposition of the spiral order of nature represented by the shell of the Burgundy snail and an architectural detail testifies to the author's aesthetic and cognitive sensitivity. Presented in the photograph are two curves, which unfold around their apexes.

Phot. 11. Concentric circles (photo by Zuzanna Legan)

This creative composition of a stone spiral (the actual creation or only the photographing) uncovers the author's sensory domination and her implied passion for Earth Art. Dominant kinaesthetic learners acquire knowledge best through activities, independent execution of tasks and direct involvement [23]. The inadequate title chosen by the author (the photograph does not present any circles) may suggest that the conclusions derived from the observation are superficial or that the author attempted an original approach, against "the rest of the world". In the latter case, the purpose of such a provocation may be to bring a new vision into the light or make it available to others [24]. As a matter of fact, the stone figure in the photograph constitutes the Archimedean spiral described by the following equation: $r(\alpha) = \mathrm{a} \cdot \alpha,$ with a being a constant number greater than zero and α being a nonnegative angle. The clearly visible constant lead between the spiral's arms is described by the following equation: $2\pi \cdot a.$

Phot. 12. Pentagonal space (photo by Robert Borzęcki)

The discovery of the extraordinary regularity of nature by the author of the photograph refers to mathematical reflections about the underlying order of the world of crystals. The theoretical reasoning proving the existence of exactly five different regular polyhedrons offered during a lesson in mathematics may be appropriate and elegant, but, in spite of the teacher's best efforts, it may be quite obscure for the student. In the meantime, the dodecahedron presented not as a cardboard model, but as naturally crystallized pyrite may radically transform student's attitude. The positive emotions evoked by the aesthetic and cognitive impression of the presented photograph increase the chance of the correct understanding of mathematical theories. The author of the photograph experienced his own (local) discovery in the world of the Platonic polyhedrons: *A group of pyrite crystals from Spain with solids limited regularly with twelve pentagonal walls (referred to as dodecahedrons).*

Phot. 13. Non-function (photo by Janusz Perzycki)

The message of the author of the photograph becomes meaningful when the image and the title are combined. The cognitive metaphor in this case relies on the process of *dual coding*, which relies on an interplay between two autonomous systems: verbal linguistic information (the title: *Non-function*) and visual (two shadows), which refer to specific notions and knowledge [1, p. 31].

Why non-function? It is unclear which value (or which shadow) should be assigned to the woman standing in the water. Mathematics textbooks at all level of education present functions. A small child, who is not yet able to count, knows how to assign plates and cups to a few people and to create a function in the process: assigning mommy's plate to mommy and daddy's plate to daddy, *etc*. We draw function graphs and study function properties at school all the time, yet the definition of function poses the greatest challenge. This photograph may be interpreted as a provocation to engage into a discussion in order to inspire reflection and a new arrangement of knowledge.

Phot. 14. A compass (photo by Anna Borkowska)

In this case, the author of the photography makes her mathematical observation by means of association. The metaphor incorporated in the title of the photograph proves to be uniquely accurate. A compass is a drawing instrument that may be used for inscribing circles or for transferring dimensions. The image presented in the photograph depicts the essence and the sense of the compass construction (the point of rest, the radius, the angle) and is especially well interpreted by dominant kinaesthetic learners. Let’s contemplate how inaccurate verbal methods based on the spoken or written word are when it comes to inscribing a circle. In order to understand such a structure, dominant kinaesthetic learners need (and are completely satisfied with) a stick firmly inserted into the sand and an evenly stretched string. In this photograph submitted to the competition, the skater’s body inscribes an arc on the surface of the ice ring. We are presented here with a distant association, which consists in combining two concepts which usually occur separately [7, p. 36-37]. The author’s creativity is probably connected with the flat characteristics of her own hierarchy of associations, which results in strong non-dominant associations.

Phot. 15. The common point of parallel lines (photo by Sara Szostak)

Please note that the content of this photograph (two trapeziums *y* with a common base) is interpreted very differently by someone who has experienced this extraordinary play of the parallelism. Looking at the glass roof, the author of the photograph was absolutely certain that the arms of the trapezium are perpendicular to the base [22, p. 53]. The author took the photograph in the Louvre Museum and added the following comment: *I cannot resist the illusion that the parallel lines shown in the photograph have a common point. Isn't this illusion an example of how the world is not entirely subject to the rules of Euclidean geometry (and in particular, it negates the Euclid's 5th postulate)?*

What we have here is a visual ontological metaphor the purpose of which is to depict aspects of the concept [25]. The title of the photograph: "*The common point of parallel lines*" itself is a provocation, as in Euclidean geometry (in school environment) parallel lines are such lines which do not have any common points. The optical illusion caused by the perspective and emphasized by the title manifests the author's internal dialogue and her reflections concerning other geometries.

Conclusions

The objective of the above presentation of selected examples of mathematical metaphors expressed through photographs submitted to The National Photographic Competition "Mathematics in Photographic Lens" was to offer an insight into the subjective creativity of the authors of the photographs. The phenomena of mathematical discovery of knowledge were brought to life during the day-to-day habitual actions, ordinary life, and automatic assignment of meaning to the reality that surrounds us [26]. Taking photographs of the presented objects "*reinforced the development of the process of seeing and imagining of mathematical objects*" [27]. Mathematical cognition, thanks to photography, came to life in the mind of the respondents as a process leading to observation (both of the natural world and of human creations) by problematization (formulation of a task, a hypothesis, a problem) for communication (selection of the optimal means of expression with the help of double coding of the thought - in photographic image and description and the title).

The finalized hermeneutic analysis leads to a conclusion that there is a need for experimental verification of efficiency of teaching mathematics on the basis of photography and for determination of the influence of mathematical photoeducation on the development of mathematical culture of the student. Research within this scope is currently conducted by The Laboratory of Didactics of Mathematics of The University of Szczecin.

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MATEMATYCZNE POZNANIE POPRZEZ METAFORY WYRAŻONE FOTOGRAFIĄ

Instytut Matematyki, Uniwersytet Szczeciński

Abstrakt: W artykule zasygnalizowano podstawy nowej metody nauczania matematyki powstającej na bazie koncepcji poznawczej człowieka i w oparciu o paradygmat konstruktywistyczny. Przedstawione przykłady prowadzonych przez 17 lat badań hermeneutycznych dotyczą analizy formułowanych problemów matematycznych w języku metafor fotograficznych. Myśli wyrażone za pomocą obrazu fotograficznego oraz tekstu składającego się z podpisu i opisu (*dual coding*) odsłaniają strukturę sieci poznawczych autorów, co ma szczególne znaczenie w tworzeniu nowoczesnej dydaktyki, która ma odpowiadać na potrzeby dzisiejszego fotospołeczeństwa. Fotoedukacja matematyczna pozwala na swobodne przemieszczanie się pomiędzy sztuką a matematyką, zakłada artystyczną wrażliwość ucznia i ożywienie jego ekspresji poznawczej w przestrzeni odległej od sali szkolnej (nad jeziorem, na podwórku, lodowisku czy podczas wycieczki do muzeum minerałów). Wykorzystuje naturalne zaciekawienie ucznia obserwowanymi zjawiskami świata przyrody i obiektami utworzonymi przez człowieka. Twórczość tego typu, opierająca się na samodzielnym odkrywaniu lub konstruowaniu wiedzy przy pomocy aparatu fotograficznego, otwiera zupełnie nową przestrzeń dydaktyki matematyki, gdyż uświadamia uczącym konkretne drogi asocjacji, prowadzące do zrealizowania procesów poznawczych w odniesieniu do abstrakcyjnych obiektów matematyki.

Słowa kluczowe: nauczanie matematyki, kultura matematyczna, fotografia poznawcza, fotoedukacja matematyczna, naukowa twórczość ucznia, zdolności kierunkowe i twórcze w matematyce