Wilhelm Ostwald's Combinatorics as a Link between In-formation and Form

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Abstract

The combinatorial thinking of the chemist and Nobel laureate Wilhelm Ostwald grew out of his activities in chemistry and was further developed in his philosophy of nature. Ostwald used combinatorics as an analogous, creative, and interdisciplinary way of thinking in areas like knowledge organization and in his theory of colors and forms. His work marginally influenced art movements like the German Werkbund, the Dutch De Stijl, and the Bauhaus. Ostwald's activities and his use of spatial analogies such as bridge, net, or pyramid can be viewed as support for a relation between information—or "in-formation," or Bildung (education, formation)—and form.

Introduction

Combinatorics as a part of mathematics is concerned with the counting of objects and with the determination of possible arrangements of objects, which may or may not be distinguishable. Their sequence may or may not have consequences (Gowers, 2008, pp. 6–7). Combinatorics was seen as part of logic by Ramon Llull in the thirteenth century. For Leibniz, combinatorics was an *ars inveniendi*. It included the idea of creating knowledge mechanically through a machine (Knobloch, 2004, p. 80) and the combination of conceptual elements independently of their meaning (Krämer, 1988, p. 89). In the tradition of Llull and Leibniz, the German chemist and Nobel laureate Wilhelm Ostwald (born in 1853 in Riga, Latvia; died in 1932 in Leipzig, Germany) wrote: "Combinatorics doesn't only replace productive imagination, but is superior to it!" (Ostwald, 1978, p. 29).[1]

Ostwald, one of the founders and organizers of the discipline "physical chemistry" at the end of the nineteenth century (Deltete, 2008; Ertl, 2009; Kim, 2008), worked from 1887 until 1906 as a professor in Leipzig and received the 1909 Nobel Prize in Chemistry for his work on catalysis,

equilibria, and rates of chemical reactions. Especially after his early retirement, he developed broad and multifaceted interests in philosophy (of nature), history (of science), and painting, color theory, and the international organization of scholarly work. The search for harmony and order in combination with his energetic imperative ("Do not waste energy, but convert it into a more useful form") was a foundation of all Ostwald's activities. In later years he developed a theory of forms to explain beauty and harmony, which can also play a role when conducting scholarly research in chemistry and other disciplines (Schummer, MacLennan, & Taylor, 2009).

Although Ostwald saw mathematics as a foundation for the unity of science, he never contributed to the mathematical subdiscipline "combinatorics" itself. Nevertheless, Ostwald has been considered one of the discoverers of logic (Ziche, 2008), which he saw as more constitutive for other sciences than for mathematics. As will be discuseed, Ostwald used the mathematical tool "combinatorics" in his work far beyond chemistry, often in a metaphorical way or as an educational tool, as a form of representation and teaching of knowledge.[2] Thus, combinatorics works in different disciplines as an analogous or similar method of thinking.

COMBINATORICS: FROM CHEMISTRY TO PHILOSOPHY OF SCIENCE

Ostwald's combinatorial thinking was influenced by his experience as a catalytic chemist. In his student years, he was impressed by the fact that it was possible to calculate the number of isometric substances in advance through combinatorics (Ostwald, 2003, p. 52). Chemistry has been described as a "combinatorial art" (Laszlo, 1999, p. 234) or as "combinatorial by essence" (Laszlo, 2001, p. 270). Today, the subfield "combinatorial chemistry" uses combinatorial methods as a form of selection to discover new molecules. The use of the term "library" in this context gives a first link between combinatorics and information: "Central to modern combinatorial practice [in chemistry] is the generation at some intermediate stage of a large set of molecules" (Hoffmann, 2001, p. 3337), which is called a "library."

In his "philosophy of nature," his philosophy of science, Ostwald looked for an empiric foundation of mathematics and the sciences. For Hauser (1951, p. 492), Ostwald's "greatest contribution to science and education was not the discovery of how to form oxides of nitrogen by passing a mixture of air and ammonia over a platinum catalyst . . . , but rather the emphasis he always placed in his writings and lectures on the need of the young generation's acquiring at least a basic knowledge of what he called 'basic philosophy.'"

The formation of concepts should occur out of experience. Typically a chemist, Ostwald aimed for an "elementary table of concepts," men-

tioning Gottfried Wilhelm Leibniz, who named this the "foundational problem of logic and philosophy of science" (Ostwald, 1911b). Then these concepts could be composed like chemical elements or compounds through systematic combination: "But we can easily make manifold arbitrary combinations of concepts from different experiences, since our memory freely places them at our disposal, and from such a combination we can form a new concept" (Ostwald, 1911a, p.18). For Ostwald, philosophy had the task to find the "general" issues of the specific sciences—like his physical chemistry within the whole chemistry. He viewed this as necessary also because of the "overload with new scholarly work and publications" [Hochflut neuer wissenschaftlicher Arbeit] (Ostwald, 1912b, p. 107). There was a need for Ostwald to reflect about general foundations of a discipline because otherwise it would not be possible to cope with information overload.

Ostwald proposed a "science of order," calling it "Mathetics," as the basis of an arrangement of the sciences orientated on the hierarchical model from Auguste Comte, which Ostwald called the "pyramid of sciences" (Ostwald, 1929). Every lower discipline functions here as a foundation or auxiliary science for the upper ones. Upper disciplines have foundations in all disciplines below. "We see that . . . we can actually dispose of all ideas, each in its own place, and that a systematic arrangement of all conceivable and possible sciences, in the order of narrowing range and increasing content of the ideas, gives us the certainty of logically encompassing all human thought and hence all the human sciences possible" (Ostwald, 1912c, p. 814). With sentences like this, Ostwald influenced the development of the "Bibliographic Classification" of the librarian Henry Evelyn Bliss. Bliss (1929, p. 393) described Ostwald's order of the sciences in the following way (in reverse order to fig. 1):

   I. Formal Sciences. Main concept: order.
      Logic, or the science of the Manifold.
      Mathematics, or the science of Quantity.
      Geometry, or the science of Space.
      Phoronomy, or the science of Motion.

  II. Physical Science. Main concept: energy.
      Mechanics.
      Physics.
      Chemistry.

 III. Biological Sciences. Main concept: life.
      Physiology.
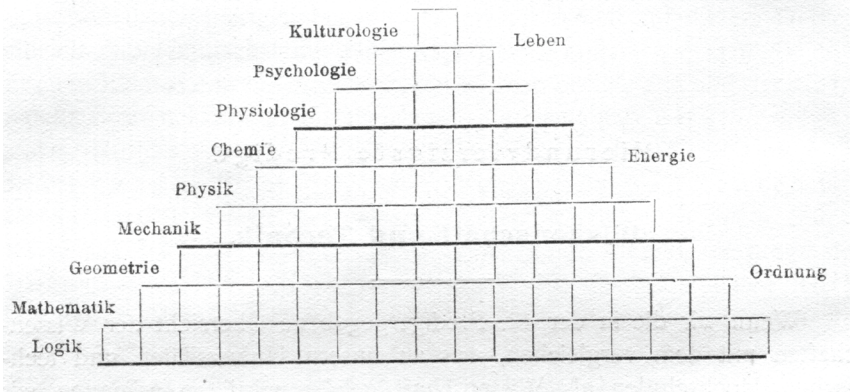   Psychology.
      Sociology.

Figure 1. Pyramid of the sciences (Ostwald, 1912a, p. 346).

Ideas about standardization, especially expressed in his ideas about paper formats, as well as in his work for a synthetic auxiliary language to facilitate international communication of science, were an outcome of his philosophical concept of order. Through his monistic worldview (Braune, 2009), in which he sought to overcome the dualism between matter and mind, Ostwald desired to create conditions for the unity of science and a seamless unity of scientific thinking with practical life.

Ostwald defined "ordering" as relating objects or concepts (Ostwald, 1905, p. 79). He also viewed his "science of order" as synonymous with combinatorics (Ostwald, 1907, p. 159). For him to combine two concepts, there existed three possibilities: first, two distinct concepts had nothing to do with each other; second, one concept comprehended the other; and third, the two concepts had an area of commonness but had a difference in their comprehensiveness or range (Ostwald, 1914a, p. 220). The combination of concepts did not occur according to combinatorial combination in the mathematical sense, which, for example, would give only six different variants when combining three concepts. For Ostwald, the combination of three concepts resulted in twelve possibilities (compare fig. 2).

After describing how concepts or terms could be combined, Ostwald (1914a, pp. 262–263) noted: "The laws of combinatorics even allow it to decompose an area of research formally and exhaustively in its branches and fields of research—by initially locating empirically the elements of the domain and then by exhaustively combining them. . . . The application of combinatorics in scholarship is far from being widespread, as it should be." A few years earlier, Ostwald (1911a, p. 71) wrote, "There is a science, the Theory of Combinations, . . . [which] enables us to obtain a complete table and survey of all possible complex concepts which can be formed from given simple ones (whether they be really elementary concepts,
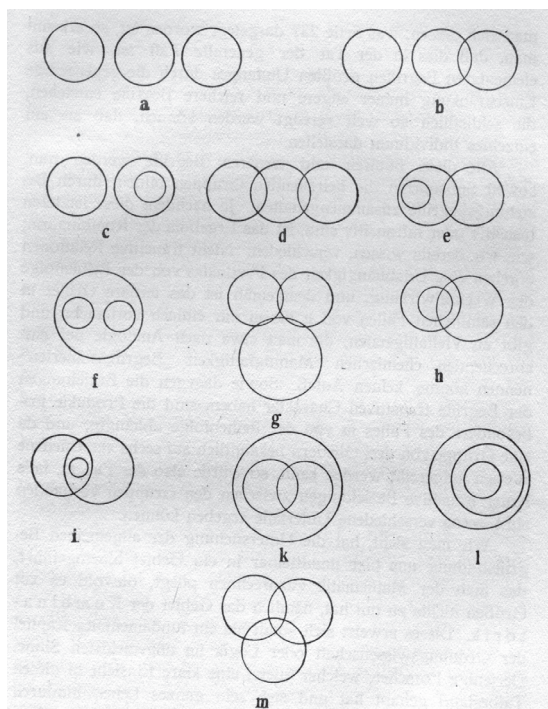
Figure 2. Combining three concepts (Ostwald, 1914a, p. 259).

or only relatively so). When in any field of science the fundamental concepts have been combined in this manner, a complete survey can be had of all the possible parts of this science by means of the theory of combinations." Ostwald (1912c) also observed the proximity of his handling of concepts or ideas to the handling of chemical elements—to some extent he viewed "concepts as particles" (van den Heuvel & Smiraglia, 2010).

Ostwald used his combinatorial method like a mechanism or algorithm for the systematization of scholarly work. For Ostwald, intellectual work is "the result of experimentation within a sometimes very long time span, which has to exhaust a large number of possible combinations before finding the right one, that means which results in the desired, well-arranged relation in the original chaos of thoughts" (Ostwald, 1914a, p. 271).

When conducting "combinatorical" research, Ostwald's first step had been to determine the position of a given problem or topic within his pyramid of the sciences (line 1, table 1, which shows Ostwald's application of the method in different contexts and mentions some of the topics discussed by Ostwald). For example, a given topic F (see table 2) may be located within the highest level, which Ostwald called sociology or "cultural

sciences" (E in fig. 3). Then, he explored the problem by going back to the basic concepts of it (line 2, table 1). By combining these basic concepts in a combinatorial way, Ostwald tried to approach the diversity and manifoldness of the complex world (line 3, table 1), relating a topic to each of the layers, which meant looking for the combination of his topic F with all other layers of his pyramid. The diverse topics created through combination had to be held together by a holistic framework (line 4, table 1), like his monistic worldview and scientific energetics.

The most general concepts of the most basic layer of his pyramid have the greatest comprehensiveness. Special concepts of the upper layers have less comprehensiveness and greater content. These are represented on every layer within the pyramid under their starting points: "Every stage has to be imagined as realized from the bottom, so that the whole pyramid consists of nested hollow cylinders or pipes." (Ostwald, 1929, p. 93). So, according to Ostwald, the subject F (see table 2) is a concept of low comprehensiveness or range, but it reaches—like the "pipe" E in figure 3—from above to below through all levels of the pyramid, and therefore it has as a concept the richest content. In this way, Ostwald got two different perspectives, from below and from above. His view was hierarchical and nonhierarchical at the same time (Ziche, 2008, pp. 152–156, 184–185).

Table 1. Ostwald's method of scholarly research

1 Treated problem or discipline	Chemistry	Information organization	Color theory	Theory of forms	Sciences
2 Constitutive components	Chemical Elements	Fragmentation to unique thoughts	Pure colors, white and black	Basic forms	Defining basic sciences
3 Combinatorics	Within the context of the periodical system	Within a classification	Ordered within a double-cone	Tesselation through symmetrical unit operations	Within a pyramid
4 Holistic theoretical framework	Physical chemistry as general chemistry	Central agency, world brain	Harmony of colors	Harmony of forms	Energetic imperative, monism

Table 2. "Pipe" for the subject F (in reverse order compared to fig. 3)

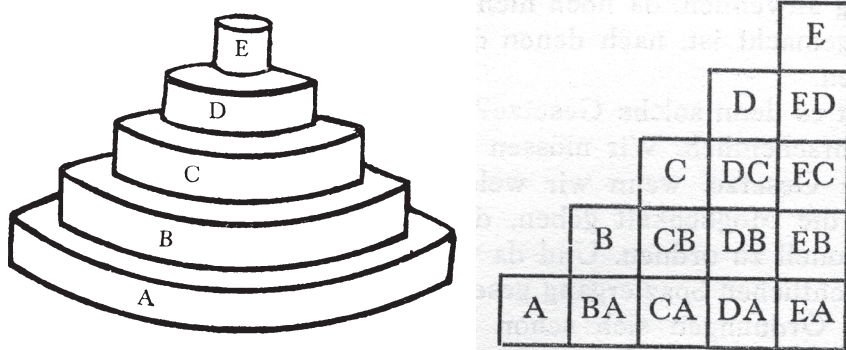|	
FA	Order and division of basic concepts concerning subject F
FB	Energetic (chemical, physical) aspects of subject F
FC	Physiological, biological aspects of subject F
FD	Psychology of subject F
FE	Sociology of subject F
F	Subject F

(From Niedersen, 1992, pp. 281–282.)

Figure 3. Combinatorics and the pyramid of sciences (Ostwald, 1929, p. 93 and p. 92).

Ostwald viewed science metaphorically as "an extremely comprehensive and manifold network, in which finally every knot is connected with every other through more or less stitches and no part can be changed, without exerting influence on all other parts" (Ostwald, 1914a, p. 287). In 1908, Ostwald wrote about the "net" of knowledge:

> [The individual's] . . . knowledge . . . is a part of the great net, and therefore possesses the quality by virtue of which the other parts readily join it as soon as they reach the consciousness and knowledge of the individual. The man . . . acquires advantages which may be compared to those of a telephone in his residence. If he wishes to, he may be connected with every body else. . . . But once such relations have been established, the possibility of telephone communication is simultaneously and automatically established. Similarly, every bit of knowledge that the individual appropriates will prove to be a regular part of the central organization, the entire extent of which he can never cover, though each individual part has been made accessible to him, provided he wants to take cognizance of it. (Ostwald, 1911a, pp. 7–8)

Application of Combinatorics to Knowledge Organization

In 1911, Ostwald founded, with others, "Die Brücke" (The Bridge), an "international institute for the organization of intellectual work," also called "world brain" by Ostwald (Hapke, 2005). This institution tried to build a comprehensive, illustrated encyclopedia on sheets of standardized formats and to improve and organize scholarly information and communication.

The principles of The Bridge seemed to fit with Ostwald's combinatorial and energetic thinking. The "monographic principle" or "principle of the independent use of the individual piece" was based—to use a chemical analogy—on the notion of "elements of thinking," mirroring the way that compounds can be broken down into constituent parts. In a book about chemical literature, Ostwald (1919) summarized many of his efforts

to organize scholarly communication and predicted new publication formats. With combinatorics at work, he developed ideas to disassemble the contents of printed journals and disseminate single papers separately. For The Bridge founders, the monographic principle followed directly from the property of mobility, which is characteristic for ideas. To apply the monographic principle in practice, the standardization of paper sheets would have been necessary.

Comparable to Gutenberg's invention of printing, which made letters moveable and able to be combined in any order, the monographic principle would allow the same for the fragments of knowledge (Bührer & Saager, 1911, p. 122). Like assembling a text from single letters, knowledge could be combined through the combination of concepts. In a similar way, Ostwald mentioned Leibniz's statement that all possible combinations of the twenty-five letters of the alphabet included the "whole wisdom of the world" (Ostwald, 1914a, pp. 260–261). Later Ostwald explicitly spoke of the analogy of "the essence of the invention of letterpress printing" to the monographic principle (Ostwald, 1921, p. 1). The combination of words from the letters of the alphabet had been a subject of study since the Middle Ages (Eco, 1995). Through Pierre Gassendi, a connection to atomism and chemistry can be proved (Meinel, 1988, p. 3).

When predicting the transformation of the book into the card index, Ostwald used his combinatorial thinking again: "If you make sure that every sheet contains only one topic, you are at once aware that you can reach an infinite combinability of the elements obtained in this way, and that you can express if necessary—depending on your purpose—any optional relation of the described facts through the spatial order of these sheets" (Ostwald, 1919, p. 96). This "one-sheet-one-topic" principle originated from one of the cofounders of The Bridge, the Swiss Karl Bührer (Hapke, 2008, p. 311), and can be found as a research principle in the work of sociologists such as Beatrice and Sidney Webb, contemporaries of Ostwald, who "established the rule that each sheet of paper must contain notes pertaining to only one single event occurring at a definite time and place" (Lepenies, 1992, p. 127–128; Webb, 1926).

The necessity to arrange the separates or index cards led back to the problem of ordering. Thus, the "technical" fragmentation of knowledge had to be kept together through a uniform standardized system of knowledge organization in the form of a classification. The Bridge used the decimal classification that was developed in 1876 by the American librarian Melvil Dewey as a shelf classification, which is still in use today (Bührer & Saager, 1912). It divides the domains of knowledge into ten subdivisions indicated by the digits 0 to 9, repeating this process again and again. Later, Paul Otlet and Henri La Fontaine, the founders of the Institut Internationale de Bibliographie in Brussels, developed the Universal Decimal Classification with an embedded combinatorial functionality.

Using implicitly Ostwald's thinking, Paul Otlet described "the law of conservation of energy: never lost, never created, all is transformation. In the book also: books conserve mental energy, what is contained in books passes to other books when they themselves have been destroyed; and all bibliological creation, no matter how original and how powerful, implies redistribution, combination and new amalgamations from what is previously given" (cited in Day, 2001, p. 15). The similarity between the bibliographic efforts of the first information pioneers such as Ostwald and Otlet may also be due to their positivistic attitudes, which saw science as a model for all other subjects. A relation of Otlet's knowledge representations to pyramidal models in the Semantic Web and Web 2.0 can be noted (van den Heuvel, 2009, p. 224).

The principle of completeness, *Restlosigkeit* (Krajewski, 2006), as The Bridge and its cofounder Bührer called it, ceased under the direction of Bührer to collect everything, for example all postcards of the town Ansbach or advertising picture cards or other ephemera like advertising stamps (Ostwald, 2003, p. 519). It became the reason for the failure of The Bridge in 1914. Advertising stamps like the ones also issued by The Bridge (see fig. 4) enabled a combinatorial representation and exploration of the world, allowing the collector of the stamps to experience "the life of the present by playing" (Saager, 1913, p. 28).

Application of Combinatorics to the Theory of Color and Forms

In applying combinatorics, Ostwald also explained the diversity of colors. In one of his many books about color theory, Ostwald mentioned explicitly his "Moderne Naturphilosophie": "I may well say that without those preparative works I would not have been able to carry out the present one" (Ostwald, 1924, p. vii). For Ostwald, his theory of colors was a quasi-practical testing and application of his theoretic scientific principles as well as a kind of proof for his assumption that creativity can be arranged (Ostwald, 2003, p. 560).

Looking at first for fundamental colors as basic elements of his color theory, Ostwald differentiated between "achromatic" (white, different values of gray, black) and colorful colors, with eight primary colors. "Therefore, any color may be regarded as consisting of a pure color of the given hue, white, and black. All three together make up the color" (Ostwald, 1930a, p. 12; Ostwald, 1969). In addition to introducing a gray scale into color, he arranged the colors in a circle, extending it to a circle with twenty-four colors. In the so-called color cone, a double-cone, color and the opposite color face each other, combining twenty-four hues with different fractions of white and black, forming a triangle (see fig. 5). Stated are the different combinations of gray tones that are added to the actual hue.

Figure 4. Advertising stamp of the Bridge (Author's photo, illustration ca. 1913).
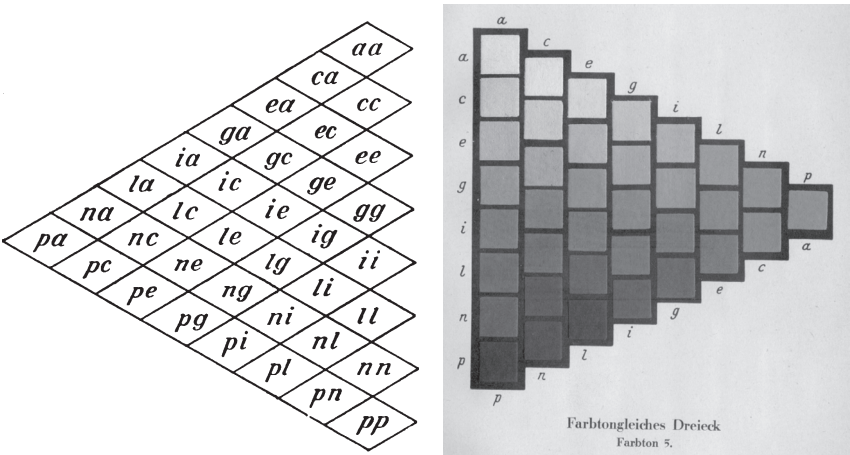

Figure 5. Combinatorics in colors (Ostwald, 1930a, p. 31; Ostwald, 1930b, table 2).

Ostwald's imperative order "legality = harmony" (Ostwald, 1923, p. 158) and his color theory marginally influenced art movements like the German Werkbund, the Dutch De Stijl, and the Bauhaus (Gage, 1993, pp. 247–263). In 1912 Ostwald joined the Werkbund, which aimed at standardizing industrial design. He published an article on "standards" in the yearbook of the Werkbund in which he called art a "social product," which made it necessary to standardize it (Ostwald, 1914b). Ostwald took part in the famous Werkbund debate, the "Typen-Streit," about the question of form in art, architecture, and design, between Hermann Muthesius and Henry van de Velde in 1914 during the annual meeting of the German Werkbund in Cologne (Campbell, 1978, pp. 57–79). During the discussion about the issue of whether the creation of form should be more influenced by standardization ("types") than by the individual creativity of the artist or vice versa, Ostwald was on the side of Muthesius and rose to speak about the closeness between artistic and scientific work (Muthesius, 1914, pp. 71–74). For Ostwald, the "type" was a kind of frame produced through the social character of art, which he also emphasized for science.

Ostwald was asked by the German Werkbund to prepare a "rational" atlas of colors. His ideas for color composition from a scientific viewpoint were combated by most contemporary artists. Nevertheless, in the first volume of the journal *De Stijl,* a review on Ostwald's "Color Primer" was published (Huszar, 1918). Two years later, this journal published Ostwald's article on the "Harmony of Colors" (Ostwald, 1920). Ostwald's theory of color was designed for commercial practice "to show the way—in the sense of his energetic demand for economy—to achieve a maximum of impact with minimum efforts of painting means" (Luther, 1933, p. 70). In the 1920s Ostwald was in contact with members of the Bauhaus, giving talks at the Bauhaus in Dessau in 1927. He was invited that same year to join the Bauhaus board of trustees (Ball, 2004). Ostwald was also mentioned by Swiss artist and Bauhaus follower Max Bill in the afterword of the German edition of Kandinsky's *Punkt und Linie zu Fläche* (Point and Line to Plane) (1973, p. 210). Nevertheless, most of the Bauhaus members remained standoffish to his ideas. Additional influences of Ostwald's ideas in art can be found in the work of Paul Klee (Aichele, 1993) and in Russian postrevolutionary art in connection with the Russian philosopher Alexander Bogdanov (Douglas, 2002).

An interesting connection between art, combinatorics, standardization, and the book formed the work of the German typographer Jan Tschichold, who argued in the 1920s for "pure forms" and clarity in the sense of the Bauhaus. He wrote, "The publications of 'Die Brücke' are among the most interesting studies in this field [of standardization]" (Tschichold, 1995, p. 97). In line with Ostwald's "combinatorial activities" in art, chemistry, and knowledge organization, art was one of the starting points of Ostwald's "chemical" life. He "was first attracted to chemistry through the

fabrication of his own oil paints, pastels, and fireworks" (Root-Bernstein, 2003; 2006).

In connection with his color theory, Ostwald was engaged in the "harmony of forms." He also published an atlas of forms (see fig. 6). Using his "combinatorial method," Ostwald created ornaments and new forms "according the laws of combinatorics" that were "all beautiful, without any exception!" (Ostwald, 1922b). The Swiss graphic artist and designer Karl Gerstner wrote a book chapter entitled "The Harmony of Forms: An (Almost Forgotten) Form System by Wilhelm Ostwald." The theory of forms "was produced late, 1922, as a complement to the theory of colors, but unlike the latter it has survived the intervening period intact. . . . Like Kandinsky a few years later, Ostwald starts from the Euclidean elements of points, line, and plane. But unlike Kandinsky he does not develop his theory on the basis of metaphysical speculations but in a rational and systematic manner. Starting from the elements, he proceeds via operations of steadily increasing complexity to results that are value-free and of universal validity" (Gerstner, 1986a, p. 76). After these sentences in the German edition of the Gerstner's book (1986b, p. 76), the following words appeared: "Programming before the computer" (Programmierung vor dem Computer). To create new forms, Ostwald looked first for basic elements of form—the triangle, the square, and the hexagon—and then filled out the plane, leaving no space when juxtaposed with three basic operations of symmetry: translation, rotation, and reflection (Ostwald, 1922a, p. 93).

"In-formation" and Form

A quotation by the German philosopher Ernst Bloch expressed the relation of information and form in the sense of this paper: "It will be perceived . . . with the aim of *in-formation* about the world and of the world itself" (Bloch, 1977, p.44). For Bloch, every process of information—seen from the perspective of an individual person wanting to inform himself or herself—included also a process of formation. Formation in regard to the individual can be read as education (*Bildung*). Formation concerning the object meant creating and designing the object (and the world). All above described activities of Ostwald, as well as his use of spatial analogies like bridge, net, or pyramid, can be viewed as support for this relation between information—also read as "in-formation," Bildung (education, formation)—and form.

"The contrast between form and information is one of the fundamental cultural dimensions which accompanies the shift from industrial to information society; or from modernism to what I would like to brand 'informationalism.' . . . And yet, as the word inFORMation implies itself, there is a hidden form-making impulse in information society" (Manovich, 2000). As this quote by the American-Russian computer artist Lev Manovich suggests, relations between information and design can be found throughout
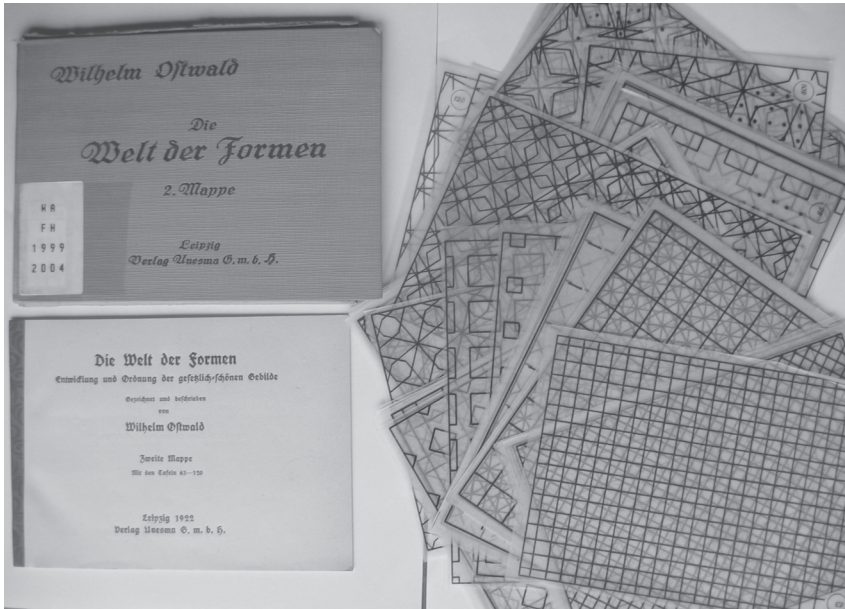
Figure 6. Combinatorics of forms (Ostwald, 1922–1923).

our present electronic world, such as in domains like information science (Lunin, Martin, & Hastings, 2009; Orna & Stevens, 1991), knowledge media design, or information aesthetics (Klütsch, 2007). Stephan (2006) explicitly mentioned Ostwald and The Bridge.

One of the exponents of information aesthetics in the 1950s was the German philosopher Max Bense, who worked at the Ulm School for Design founded by Max Bill, quoted earlier in this article. The activities of Bense's successor at Ulm underlined the "hidden," analogic-combinatorial connection between information and design: Horst Rittel, later professor of design in Berkeley (Rith & Dubberly, 2007), cowrote with Werner Kunz a book on the foundation of information science in Germany (Kunz & Rittel, 1972).

An additional quote by Manovich shows that information aesthetics can be understood as a part of information literacy: "Rather, *info-aesthetics* refers to various new contemporary cultural practices which can be best understood as responses to the new priorities of information society: making sense of information, working with information, producing knowledge from information" (Manovich, 2005). Ostwald was aware that teaching research skills combined with enabling effective use of libraries was important (Hapke, 2008, p. 317–318). He believed that "the art of discovery" should become "a part of the intellectual inventory of everyone" (Ostwald, 1910, p. 124). He suggested that teaching centers should be

created at technical universities to improve techniques for the presentation of engineering knowledge and that these should be integrated into engineering education (Hapke, 2008, p. 318).

Throughout his life, Ostwald was engaged in educational activities (Hapke, 2009), first as a professor in higher education at the university and later as an activist for education reform with connections to the movements for progressive education. In this regard, Ostwald used combinatorics as a tool for heuristics and systematics (Luther, 1933, p. 61), a method to identify new relations and analogies, and a method for creativity. When writing his famous "Lehrbuch der allgemeinen Chemie" (1885–1887), a first foundational work in the new discipline "physical chemistry," Ostwald observed that when ordering and systematizing a discipline, new questions and problems will be visible. Later he wrote: "Thus combinatory schematisation serves not only to bring the existing content of science into such order that each single thing has its assigned place, but . . . also point[s] to the places in which science can be completed by new discoveries" (Ostwald, 1911a, p. 73). In the tradition of Llull and Leibniz, Ostwald noted: "What is performed by fantasy, by creation out of the core, is limited to a novel combination of existing components, also in case of the most brilliant idea" (Ostwald, 1929, p. 29). Ideas, discoveries, and new facts in research had to be combined with diverse existing ones to create new insights. His idea on creativity sounds very similar to modern alternative views of copyright and intellectual property within the "Creative Commons" licenses (http://creativecommons.org): "Share, reuse, and remix—legally." Today, research in the area of "psychology of science" takes the role of combinatorics in creativity and innovation for granted (Boden, 2008; Simonton, 2009).

For Ostwald, combinatorics functioned as a tool to justify, as well as to improve in a scientific way, the organization of knowledge as information and art as form. As an exponent of scientism and positivism, Ostwald conveyed methods developed in chemistry to other disciplines. The "daily work in technology and science should keep the need to refresh the intellectual eye in such a way that it occasionally inverts the enforced close position with a quite expanded wide position" (Ostwald, 1929, p. 7). In line with this quote and seen from a modern pluralism of the sciences, Ostwald's analogous use of combinatorics can be read as a historical trial to facilitate scholarly diversity and to promote interdisciplinarity.

Applying his combinatorial logic in different fields of knowledge, Ostwald was able to build complex structures out of simple elements (see table 1). Ostwald understood the creative organization of concepts, the handling of information, and the building of knowledge through combinatorics as a formal process to transcend disciplinary boundaries and to innovate research in these disciplines. In line with his use of spatial metaphors such as the pyramid, the "bridge" (Ostwald, 1905, p. 13), and

the "net" when describing scholarly work and organizing scholarship, his activities ought to build bridges between the scholarly disciplines. Wilhelm Ostwald himself "stands out as a phenomenal combination, not only of the scientist and the philosopher, also of artist, linguist, and writer, who squandering no energy, but conserving it, applied his major interests to one another" (Wall, 1948, p. 118).

NOTES
1. Quotations from German texts were translated by the author of this paper.
2. The idea for this paper grew from a poster at the International Conference on Analogous Spaces: Architecture and the Space of Information, Intellect, Action at the University of Ghent, Belgium in May 2008. It was further developed in German papers (Hapke, 2009; Hapke, 2011) at two conferences in the context of the research project Rekonstruktion der wissenschaftsphilosophischen Diskurse in Ostwalds "Annalen der Naturphilosophie" of the Saxonian Academy of Sciences and Humanities in Leipzig, which was funded by the Saxonian Staatsministerium für Wissenschaft und Kunst. These two papers contain a more detailed view on Ostwald's educational activities, his methods of scholarly research, and his use of combinatorics. I am grateful for support by the organizers of all three conferences, but especially I thank Wouter Van Acker for valuable comments to improve this text.

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