Agnieszka Dąbrowska*

Interdisciplinarity as the Key to Efficient Education for Sustainable Development: Main Benefits and Challenges – A Nanotechnology Case Study

Abstract. Nowadays, one may observe a growing interest in sustainable development as the auspicious way to resolve global civilisation problems (www.undp.org). This leads to the increasing role of proper Education for Sustainable Development (ESD). Although there are many approaches to the strategy of efficient teaching (UNESCO 2012), in times of narrow specialization interdisciplinarity is frequently undervalued (Klein 1990). In this paper, the author brings attention to the question of interdisciplinarity in a broader context: its constantly changing definition, common ground with sustainability, main advantages of such a way of thinking, crucial difficulties, and hints aimed at how to introduce it to one's own teaching tools. As a case study, the teaching of nanotechnology (Meyer 2001) will be used to provide additional examples, share experiences, and make the connection between theory and practice. The aim is to disseminate the idea of interdisciplinarity as a key to efficient ESD in many domains.

Keywords: interdisciplinarity, ESD, teaching strategies, sustainable development, nanotechnology, new materials

1. Introduction and definitions: interdisciplinary versus sustainable

Looking back in time at the beginning of the concept of interdisciplinarity one may intuitively focus on the Renaissance period in the history of art and science. Although Leonardo da Vinci (Fig. 1) is the first, intuitive association, the multidisciplinary approach to life and science dates back to the Ancient Greece [Sam-

* University of Warsaw, Faculty of Chemistry, Laboratory of Nanomaterials Chemistry and Physics, e-mail: a.d.rumik@gmail.com, phone: +48 22 822 02 11.

bursky 1962]. First nature philosophers [Heller & Pabjan 2014], as distinct from their ancestors looking for practical solutions, were truly cross-disciplinary people seeking to understand the general roles of the whole Universe without dividing it in a spectrum of separated topics. They even used to submit empirical data to the paradigm of harmony and beauty [Platon 1986]. Although such a method is fortunately no longer valid, one should agree that it indisputably had one advantage. Taking a philosophical view of reality assured a holistic vision of the world as a conclusion of "scientific" delving [Arystoteles 1968]. To some extent, this inclusive approach was continued in the medieval Europe, however, only in the late Middle Ages, after an intellectual stagnation [Lindberg 1978]. Although first universities (*studium generale*) introduced different subjects [Wróblewski 2006], their aim was still to cover all up-to-date knowledge about the world and students' formation was based on the holistic vision. One might achieve it due to a logical program construction: first years dedicated to general formation (after the school *trivium* with logic and grammar, students moved on to the *quadrivium* based on arithmetic, geometry, astronomy, and music) and specialization (in medicine, theology, or law) for older students. To some extent the general base of this system is still used [Lepszy 1964]. Obviously, this is a very simplified picture as, even in the Middle Ages, the conception of education was not homogenous at different levels and in different parts of Europe. One may find it interesting that from two dominating types of universities, the Paris and the Bologna, the first one dominated in many more regions. Within the second system, the professors' rights were limited and their position rather insignificant: rich students could even judge and punish them for inadequate behaviour during classes [Moulin 2002]. Among the major drawbacks of this type of organization one may point out: low efficiency (on average only one in four students finished the first three years of education and just one out of twenty reached the master level), small number of students, and long education (even more than 8 years to obtain the doctoral title in theology). Despite the above-mentioned problems, that was the last moment in history when all educated people had the same background, which is the key factor in interdisciplinary communication.

During centuries, as the number of discovered facts and laws of nature increased, first attempts at specialization had to be introduced. After the Renaissance model of broad and interdisciplinary education, the Enlightenment started to create more one-discipline specialists than multidiscipline general knowledge masters. That was directly related to the new discoveries and enabled an even faster growth in particular disciplines: physics, medicine, natural science. This tendency, together with the growing number of students due to mass education, caused, at the end of 20th century, separation of knowledge into many different disciplines. Although the majority would agree with Richard Feynman, who claimed that "we may divide sciences into chemistry, physics, mathematics, and

Figure 1. Leonardo da Vinci (15 IV 1452 – 2 V 1519) is seen by many as the interdisciplinarity icon; however, this symbol may be a bit too schematic for proper understanding of the term "interdisciplinary"; the "foggy" picture of the wax figure of the "master"

Source: Wax Museum in Rome – Museo delle Cere (photo by A.D. Rumik).

geography, but Nature does not know anything about it," the problem of how to integrate all wide knowledge in one subject accessible for a single human being remains unsolved. What is even more alarming is the enlarging gap between human and natural science. Among other factors (fast expanding facts resources, thousands of new papers published every day, sophisticated and detailed "theories on the edge") the jargon often disables any communication between specialists working in different fields. It occurs sometimes even if the subjects of their scientific investigations remain the same. For spectacular success of modern technologies and growing life standard, the price of losing the holistic vision of the world and humanity is to be paid. Is that really inevitable?

In the 20th and 21st century, the growing awareness of the above-mentioned problems developed parallel to the revolution in information management [Gleick 2012] and common understanding of transgressing planetary boundaries [Rockström et al. 2009]. The lack of balance needs to be addressed. As a consequence, one may observe a growing interest in sustainable development postulates. All of them, promoting mature and responsible approach to the future of our planet and civilisation, are in perfect agreement with the vision of a citizen having interdisciplinary education. Considering the factors that caused narrow specialization during history, it is apparent that the return to the Renaissance model is no longer possible (for instance due to the limited life span of humans that is far below the time needed to acquire all known scientific wisdoms). On the other hand, nowadays, because of significant progress in understanding and processing of information [Shannon 1993], some new solutions and opportunities are available. Easy access to facts via internet and facilitated information distribution and communication methods allow for faster and more efficient knowledge building together with cooperative team working. Instead of being a "walking encyclopedia" of collected and memorized facts one may dedicate time to properly integrate information, create links and, in a critical and creative way, filter data not memorized but taken from outer sources. The so-called "people bridges" help to facilitate cooperation between world leading specialists and create models for a fruitful life in the episodic modern world. They are necessary to realize the most important "sustainable wishes" as terms and conditions of sustainable development require a holistic approach to humans and their environment, underlining the connection between each single action and decision. On the other hand, the new visible trend stressed in publishing and in project design, the "interdisciplinary approach" in research, is in many cases just traditional work of many experts brought together without any particular conceptual integration of different disciplines. There are also numerous attempts to quantitatively describe this phenomenon [Morillo 2001]. As proper, conscious interdisciplinary teaching is not to be undervalued in creating open-minded scientists, let us now examine this topic more extensively.

2. Key concepts and case study (introduction to nanotechnology): from theory to practice

Before discussing interdisciplinarity as the key to efficient ESD, it is worth unscrambling and clarifying related notions. One may distinguish (according to any dictionary, e.g. Collins or Webster):

– crossdisciplinary (viewing one subject from the standpoint of another),

– multidisciplinary (the combination of several content areas that are concerned with one problem, but without intentional integration),

– plurdisciplinary (the combination of related content areas, e.g. math and physics),

– transdisciplinary (beyond the scope of the disciplines; to start with the problem and bring to bear knowledge from the disciplines),

– curriculum integration / thematic teaching (terms used to describe teaching methods that include interdisciplinary studies),

and finally:

– interdisciplinary (combining or involving two or more academic disciplines or fields of study).

What is crucial in the interdisciplinary approach to any topic is the ability to view the problem from different perspectives, discuss various points of view, widen horizons, introduce a broad context, perceive complexity and the system as a whole; awareness of action consequences and responsibility, deep understanding of the process, and efficient purpose realization are also of importance. In interdisciplinary teaching methods, achievements, reasoning, and language from more than one academic discipline might be used. In this type of learning the additional value is gained since the final effect go beyond the sum of components. The aim is to create connections and enable observation of new phenomena. It is also a homocentric way of studying. Assuming that the sustainable development implementation would be the aim, interdisciplinarity might enlarge efficiency of dealing with various tasks.

Taking all that into account, the suggestions for efficient ESD would be the following:

– Providing examples from different disciplines,
– discussing problems from various points of view,
– making consultations with experts from many fields,
– working on sources taken not only from SD materials,
– using blended teaching,
– studying various cases (both from different disciplines and one particular done by experts with diversified backgrounds),
– encouraging students to gain general knowledge of disciplines far related to their professional domain of interest,
– training in information selection,
– creating links between disciplines (with proper jargon translation),
– stimulating interests,
– basing on peer reviews and student-to-student teaching,
– organizing debates of representatives of human science together with natural science,
– teaching the basics of efficient communication [Peters 1999], information management, and knowledge creation [Sunstein 2006].

To better illustrate those ideas let us consider for a moment a concrete teaching subject: nanotechnology. It is a valid example because of its huge, and still growing, importance in modern society [Roco et al. 2002]. This science on the edge was truly interdisciplinary from the very beginning, combining chemistry, physics, material engineering, technology, biology, and others. Initially broadly-based it subsequently split into a set of narrow, specialised fields [Schummer 2004]. What was characteristic was rediscovering and reusing known concepts but in a new context. On the one hand, there are currently very few branches to

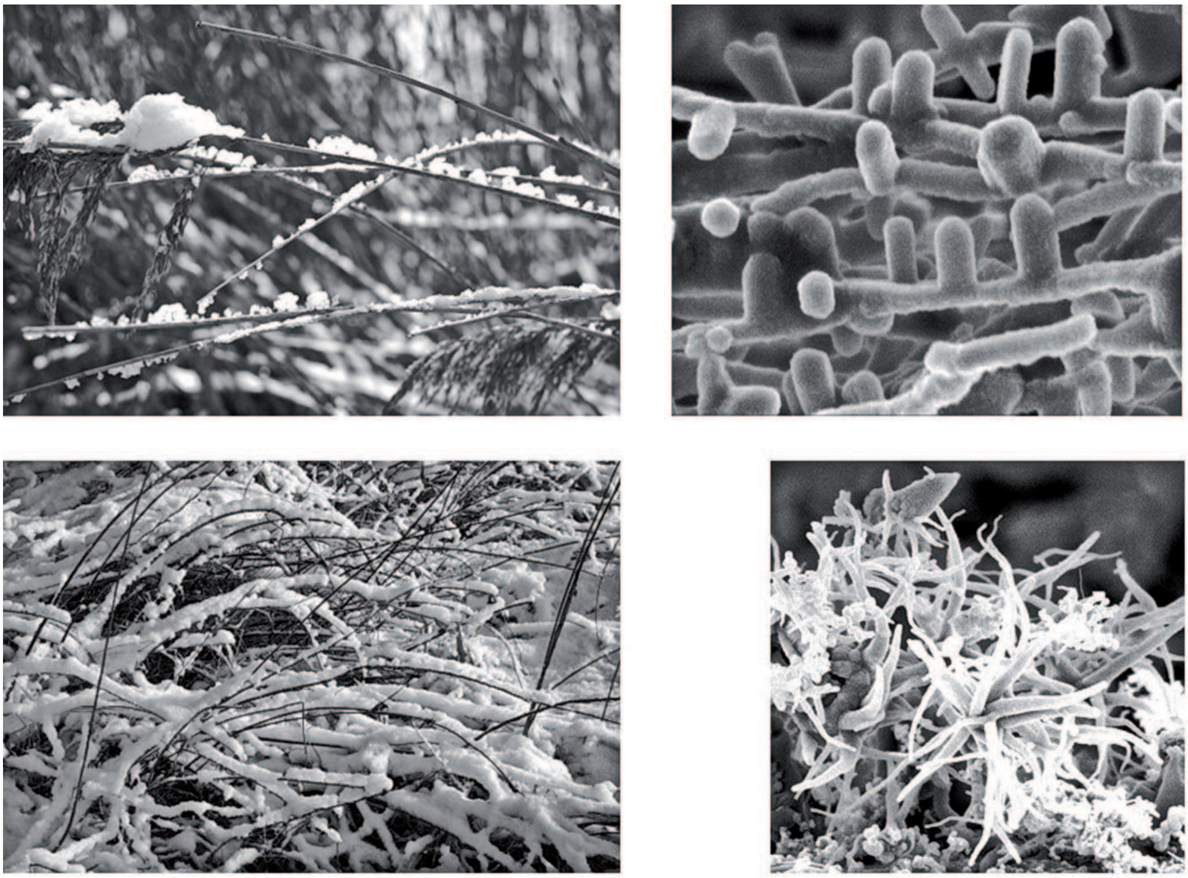

Figure 2. The relationship between natural inspiration (on the left, fresh snow on branches) and nanomaterials (on the right, SiC nanocombs and modified SiC nanowires); the ability to perceive analogies is one of the main benefits of interdisciplinary training

Source: SEM from University of Warsaw (photo by A.D.Rumik).

develop as fast and dynamically as nanotechnology, on the other, fringe opinions about "nano" may be observed among non-specialist. There is still a lack of common knowledge about the possibilities and drawbacks of nanotechnology. Huge enthusiasm from the business perspective results in mass production of nanomaterials without regard to future consequences: their potentially significant impact on the environment (the majority of waste sooner or later ends in the sea) and human health. At the other end of the spectrum, there are suggestions to abolish and be wary of everything that is (or may be) "nano" without precisely defining and understanding what it is. Both approaches, as completely neither sustainable nor balanced, are not recommendable. There is a strong need for conscious and well-designed strategy of future development of nanomaterials based on the people's awareness and real needs. To make it efficient, education of society is crucial. What about specialists? Let us imagine a scenario in which a leading nanotechnologist would be concurrently a sustainable development aware person. It is not a utopia since education will provide physical chemists with examples from other disciplines. The open task how to use nanotechnology for solving global problems should be introduced. As a result, nature might be the best inspiration for materials design and engineering. Biomimetics is a successful example [Raz 2013].

Finally, nanotechnology is even more related to the idea of sustainable development than one may presume. In this place it is worth mentioning the Sustainable Nanotechnology Organization (SNO) that, as written on their website: "is a non-profit, worldwide professional society comprised of individuals and institutions that are engaged in:

- Research and development of sustainable nanotechnology,
- implications of nanotechnology for environment, health, and safety,
- advances in nanoscience, methods, protocols, and metrology,
- education and understanding of sustainable nanotechnology,
- applications of nanotechnology for sustainability,

SNO's purpose is to provide a professional society forum to advance knowledge in all aspects of sustainable nanotechnology, including both applications and implications, societal and economic aspects."[1] This example illustrates a cross-disciplinary action worth promoting. There are also many information centres and educational initiatives[2] with valuable training materials to be found.[3]

3. Challenges and drawbacks

Although the list of benefits seems meaningful, interdisciplinary teaching is not a trivial task. In modern society strong demand for specialists, absolute experts in a narrow domain is constantly increasing. Economic reasons will dominate. As a consequence, interdisciplinary teaching, giving broad and extended background to the "practical tools," may encounter strong opposition from market- and success-oriented students. Additional requirements and necessary effort may, at the first sight, seem redundant and too time-consuming. This obstacle is easier to overcome in the case of commercial courses and training programs for adults, where consciousness of the importance of long-lasting results instead of an imminent, superficial effect is observed in people investing in their life-long education. In both cases one may also base on the innate human curiosity stimulating interests and hobbies. Moreover, fast developing tutoring [Czekierda 2015] and mentoring tools might be useful in creating multidimensional and long-lasting professor-student relationships, which are so indispensable for interdisciplinary

[1] www.susnano.org/index.html [15.01.2016].

[2] www.nanotechproject.org [15.01.2016].

[3] www.nanohub.org/groups/gng/training_materials [15.01.2016].

education. Another challenge is related to teachers' efforts as they have to be at least doubly well-prepared. In addition, they will need to keep their knowledge of various disciplines up-to-date, which, in view of the rapidly growing number of published papers, may seem a "mission impossible". Here the key would be proper content selection. Links between domains are also fruitful. Information integration, despite the jargon and specific tools, and common practices typical for each field, is possible. Reference to experts can always be made. There is always an optimum number of people that may teach a subject together from different perspectives. Finally, one has to bear in mind that interdisciplinary is not a synonym of chaotic – a purpose-driven approach should always be maintained in order not to get lost in variety.

4. Conclusion and final remarks

Taking into account all advantages, positive feedback and, especially, long-term benefits of interdisciplinarity, one may conclude that, despite all numerous challenges, it is worth teaching further generations in that manner: widening horizons, presenting problems from different perspectives, and creating a holistic vision of the world. As the theme is far too broad for one introductive article, the variety of up-to-date literature might be helpful [Andersen 2016; Foley 2016; Pittman 2016; Urea 2015]. Individual predispositions are needed and, initially, a lack of support and understanding due to the inertia of the system must be overcome, but sustainable goals, as Rome, "are not built in a day."

References

Andersen H., 2016, Collaboration, interdisciplinarity, and the epistemology of contemporary science, *Studies in History and Philosophy of Science*, Part A, vol. 56: 1-10.

Arystoteles, 1968, *Fizyka*, Polish translation: K. Leśniak, Warszawa: PWN.

Czekierda P., Fingas B., Szala M., 2015, *Tutoring. Teoria, praktyka, studia przypadków*, Warszawa: Wolters Kluwer Polska.

Foley G., 2016, Reflections on interdisciplinarity and teaching chemical engineering on an interdisciplinary degree programme in biotechnology, *Education for Chemical Engineers*, vol. 14: 35-42.

Gleick J., 2012, *Informacja. Bit, wszechświat, rewolucja*, Kraków: Znak.

Heller M., Pabjan T., 2014, *Elementy filozofii przyrody*, Kraków: Copernicus Center Press.

Klein J.Th., 1990, *Interdisciplinarity. History, Theory & Practice*, Detroit: Wayne State University Press.

Lepszy K., 1964, *Dzieje Uniwersytetu Jagiellońskiego w latach 1364-1764*, t. 1, Kraków: PWN.

Lindberg D.C., 1978, *Science in the Middle Ages*, Chicago: University of Chicago Press.

Meyer M., 2001, Patent citations in a novel field of technology: An exploration of nanoscience and nano-technology, *Scientometrics*, vol. 51: 163-183.

Morillo F. et al., 2001, An approach to interdisciplinarity through bibliometric indicators, *Scientometrics*, vol. 51: 203-222.

Moulin L., 2002, *Średniowieczni szkolarze i ich mistrzowie*, Polish translation: H. Lubicz-Trawkowska, Gdańsk – Warszawa: Marabut.

Peters J.D., 1999, *Speaking Into the Air. A History of the Idea of Communication*, Chicago: University of Chicago Press.

Pittman J. et al., 2016, The evolution of interdisciplinarity over 20 years of global change research by the IAI, *Current Opinion in Environmental Sustainability*, vol. 19: 87-93.

Platon, 1986, *Timajos, Kritias albo Atlantyk*, Polish translation: P. Siwek, Warszawa: PWN.

Raz J., 2013, *Biomimetics*, Berlin: Walter de Gruyter.

Rockström J. et al., 2009, Planetary Boundaries: Exploring the Safe Operating Space for Humanity, *Ecology and Society*, vol. 14(2): 32.

Roco M.C. et al., 2002, *Converging Technologies for Improving Human Performance: Nanotechnology, biotechnology, Information Technology and cognitive Science*, Arlington, VA: National Science Foundation.

Sambursky S., 1962, *The Physical World of Greeks*, New York: Collier Books.

Shannon C.E., 1993, *Collected Papers*, New York: Oxford University Press.

Schummer J., Multidisciplinarity, interdisciplinarity and patterns of research collaboraton in nanoscience and nanotechnology, *Scientometrics*, vol. 59(3): 425-465.

Sunstein C.R., 2006, *Infotropia. How Many Minds Produce Knowledge*, Oxford: Oxford University Press.

UNESCO, 2012, *Education for Sustainable Development. Sourcebook*, Paris.

Urea R., 2015, The Perceived Significances of Interdisciplinarity at Students in Educational Sciences, *Procedia-Social and Behavioral Sciences*, vol. 187: 228-233.

Webster Dictionary, 1993, Cologna: Könemann.

Wróblewski A.K., 2006, *Historia fizyki*, Warszawa: WN PWN.

www.nanohub.org/groups/gng/training_materials [15.01.2016].

www.nanotechproject.org [15.01.2016].

www.susnano.org/index.html [15.01.2016].

www.undp.org [15.01.2016].

Interdyscyplinarne podejście jako klucz do efektywnego przekazywania wiedzy zgodnie z koncepcją zrównoważonego rozwoju: korzyści, wyzwania oraz analiza zagadnienia na przykładzie nauczania nanotechnologii

Streszczenie. Obserwowany współcześnie wzrost zainteresowania koncepcjami zrównoważonego rozwoju wynika z pokładanych w nich nadziei przy rozwiązywaniu globalnych problemów cywilizacyjnych. Związana jest z tym konieczność wypracowania właściwych metod nauczania, które służyłyby wdrażaniu głównych postulatów zgodnie z założeniami zrównoważonego rozwoju. Wśród wielu podejść na uwagę zasługuje interdyscyplinarność, często niedoceniana we współczesnym świecie słynącym z wąskich specjalizacji. W artykule tym zajmujemy się w szerszym kontekście tym zagadnieniem: rozważając ewolucję interdyscyplinarności na przestrzeni stuleci, jej zbieżność z pojęciem zrównoważenia oraz główne korzyści i problemy związane z interdyscyplinarnym nauczaniem. Konkretne wskazówki i rozwiązania zostaną przedstawione na przykładzie nanotechnologii – nowoczesnej dziedziny czerpiącej z wielu dyscyplin naukowych. Celem jest rozpowszechnienie koncepcji interdyscyplinarnego nauczania jako pełnej i zgodnej z założeniami zrównoważonego rozwoju edukacji specjalistów z różnych dziedzin.

Słowa kluczowe: interdyscyplinarny, zrównoważony rozwój, techniki nauczania, nanotechnologia, inżynieria materiałowa