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Interdisciplinary Approaches in Engineering Education: Preparing Young Minds for Complex Challenges

Ille C. Gebeshuber *. Pia M. Graves **. Inez Wardzinska *. Ruth Mateus-Berr ****. Breda Walsh Shanahan *******

** Institute of Applied Physics, TU Wien, 1040 Vienna, Austria (Tel: 43-1-58801-13483; e-mail: gebeshuber@iap.tuwien.ac.at).*

*** Institute of Applied Physics, TU Wien, 1040 Vienna, Austria (e-mail: graves@iap.tuwien.ac.at).*

**** Institute of Applied Physics, TU Wien, 1040 Vienna, Austria (e-mail: inez.wardzinska@gmx.at).*

***** Center for Didactics of Art and Interdisciplinary Education, University of Applied Arts Vienna, 1030 Vienna, Austria (Tel: +43-1-711332732; e-mail: ruth.mateus-berr@uni-ak.ac.at).*

****** Department of Education and Lifelong Learning, South East Technological University, Ireland (e-mail: Breda.Shanahan@setu.ie)}*

Abstract: While interdisciplinary research in STEM (science, technology, engineering and mathematics), first introduced by bacteriologist R. Colwell, is a vital and exciting part of the dynamic landscape of contemporary research, the combination of the arts and the sciences, or STEAM (science, technology, engineering, arts and mathematics), is recognized as pedagogical innovations of the 21st century. The creative industries are considered as intellectual capital and are growing areas of the innovative economy (Melikuzievich, 2024). Bringing together artistic and scientific approaches is not only inspiring innovation, but combining efforts to address the complex challenges that define our time. Integrating artistic methods into research and teaching makes science more accessible by translating scientific concepts into relatable narratives or vivid visuals, resulting in reaching a more diverse audience. Bridging arts education and STEM education also encourages public engagement since it is more open for dialogue and evokes responsiveness and critical thinking (OECD, 2023). These outcomes align perfectly with UNESCO's "The Global Education 2030 Agenda", aiming for inclusive education and equity, which underlines the importance of these interdisciplinary approaches (UNESCO, 2019). In this paper even more advantages of combining the arts and the sciences are shown, ranging from increased resourcefulness to the creation of cutting-edge solutions. By spotlighting best practice examples in both teaching and research, it endeavours to provide a comprehensive exploration of the transformative potential that lies at the intersection of artistic expression and scientific inquiry. The goal is to underscore the many benefits and immense potential that STEAM initiatives hold for the advancement of knowledge, education and innovation.

Keywords: engineering education; interdisciplinary research; collaboration; outreach; broader impacts; sustainable model; diversity; inclusion, design thinking

1. INTRODUCTION

Interdisciplinary approaches that bridge arts education and engineering education can significantly narrow educational gaps and enhance skill development by fostering a holistic learning environment. By integrating the creative problem-solving and critical thinking skills inherent in the arts with the technical and analytical rigor of engineering, students are equipped with a more versatile skill set. This blend encourages innovation, as learners are exposed to diverse perspectives and methodologies, enabling them to approach problems with greater creativity and resourcefulness. Such cross-disciplinary education promotes adaptability, collaboration and the ability to communicate complex ideas effectively across different domains. Moreover, it prepares students for the increasingly interdisciplinary nature of modern challenges, where solutions often lie at the intersection of fields, thereby empowering them to become more effective problem-solvers and innovators in a rapidly evolving world.

'*Building diverse communities around learning to collaborate and collaborating to learn plays an important role in developing a sustainable model to engage researchers and students in problem solving at different levels.*'

'*Curiosity, creativity, connections, communication and collaboration are tools that drive effectiveness and success in reaching goals.*'

(Duncan and Pasik-Duncan, 2022)

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Figure 1. Chocolate exhibiting iridescence in rainbow hues due to the transfer of microstructures from a compact disc (CD) onto its surface. This phenomenon is a direct consequence of the interaction between light and the micrometer scale features on the chocolate, showcasing an experiment bridging science and the arts.

"Art and design as social fabric" (Mateus-Berr, 2015) discusses how art and design serve as catalysts for innovation and societal engagement during crises and changes. The work presents a case study on how these disciplines address human needs and co-create innovative solutions with specific groups, focusing on shelter and emotional evocation through material exploration. The study highlights interdisciplinary approaches, participatory research and the development of new textile objects for women's shelters and refugees, emphasizing education's role in fostering interdisciplinary teamwork and societal responsibility.

Drawing on best practice examples from Austria (Fig. 1) and based on theoretical foundations presented by the co-author from Ireland, this paper highlights best practice examples regarding the preparation of young minds for the complex challenges of tomorrow, via interdisciplinary approaches in engineering education.

2. INTERDISCIPLINARY TERTIARY EDUCATION IN ARTS AND ENGINEERING

Advocating for a curriculum that bridges the gap between engineering and the arts contributes to the discourse on the future of engineering education. It calls for educators, policymakers and industry leaders to embrace and implement interdisciplinary approaches, thereby preparing young minds to navigate and address the complex challenges of our time (van den Beemt et al, 2020) (Gibson and Ewing, 2020).

Interdisciplinarity "has been linked with attempts to expose the dangers of fragmentation" in a century, where knowledge in science doubles every two years, it should uncover and develop connections between disciplines, "re-establish old connections" and create innovative solutions (Klein 1990, 196). She argues that the basic structure of interdisciplinarity was since its beginning a "inseparable implication of disciplinary thought" (Klein 2005, 20). In her opinion (Klein 1990, 188), interdisciplinary approach is a process for achieving an integrative synthesis, "a process that usually begins with a problem, question, topic or issue."

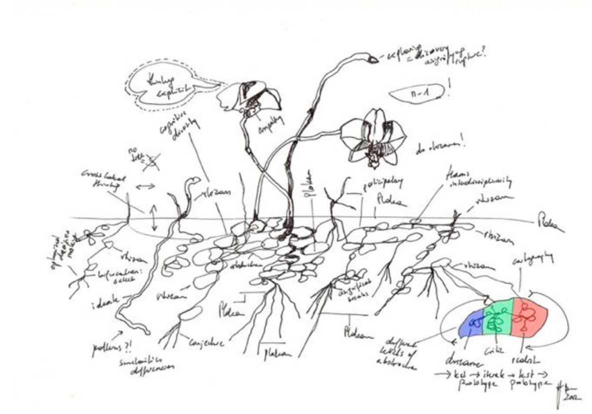

Figure 2. Designrhizom characterizing a creative process (Mateus-Berr, 2020).

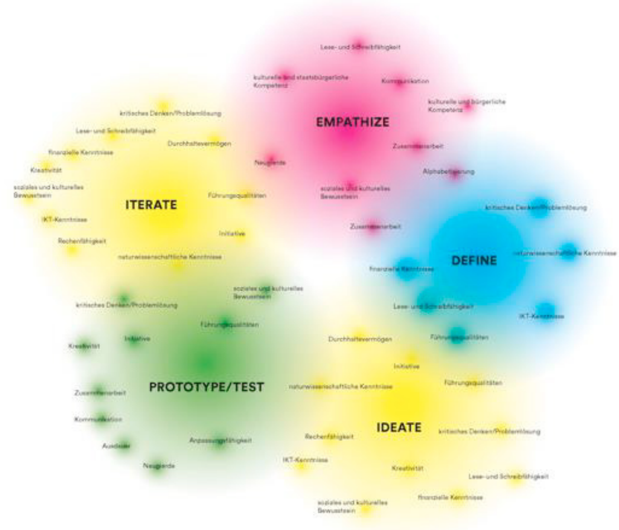

Figure 3. Design thinking characterizing a creative process (concept: Ruth Mateus-Berr, graphics: Pia Scharler).

An essential part is problem-solving through transgressing disciplinary language and world view. Klein (Klein 1990, 188-189) described steps: defining, determining, developing, specifying, engaging, gathering, resolving, building and maintaining, collating, integrating, confirming or disconfirming, deciding which are similar to the steps of Design Thinking methodology, which are supplemented by teamwork (Mateus-Berr, 2020) (Figs. 2 and 3).

Design thinking is seen as an essential way to cultivate 21st century skills, according to Li and Zhan (2022, 8), who conducted a meta-study of the application of design thinking (43 SSCI peer-reviewed journal papers with 44 studies) in the school context. They note that the need and interest in introducing primary and secondary schools to design thinking has increased by almost 30 percent since 2017. For the most part, the method is used for STEM in the younger grades. Interestingly, this method was hardly used in subjects such as technology and design, but rather in science and engineering. Arts and design must re-claim the methodology.

In the evolving landscape of industries, where dynamic work practices align with scientific and technological advancements, the format of educational models has also experienced dynamic changes. The theorists who inform the practice of interdisciplinary education consist of a) David A Kolb, b) Benjamin Bloom and c) Lev Vygotsky. Their combined theories form the foundation of interdisciplinary methods used in the teaching and learning examples shown here. To explain this further the following is an outline of each theorist and how their theory is related to practice.

a) Kolb and Fry developed the Experiential Learning Model (ELM) in the 1970s. It is based on individual and societal change due to experience founded on the four concepts of: concrete experience, reflecting on the experience, creation of abstracts from the experience and testing the new concepts. This process was revised in 2011 and is seen as the Experiential Learning Style Inventory which is cyclical and can be initiated at any stage within the cycle (Kolb and Kolb, 2011) (Fig. 4). This demonstrates the process of experimentation and revision used in all experimental scientific studies of trial and error.

b) Bloom's Cognitive Domain Taxonomy states that within the hierarchical pyramid of his design the acquisition of *knowledge* is the first step, followed by *comprehension, application, analysis, synthesis and evaluation* (Bloom, 1956). The last two steps can often overlap but the final goal is to 'create' a new concept or process different to that which went before. In the examples shown here the concepts of combining knowledge from different disciplines has interacted to create a new concept or a new version of teaching showing results from a mixture of two disciplinary knowledge bases.

c) Vygotsky's Zone of Proximal Development (Fig. 5) has been built on socio-cultural theories borne from the concept that learning is a social process and one which is improved with interaction and is an integral component of learning leading to creativity and advancement of original concepts. In collaborative and context-specific learning environments, Vygotsky discussed the interpersonal processes between people which transform individuals, through collaboration, to higher levels of development. One of the most common methods of using STEAM is Design Thinking, which fulfils interdisciplinary requirements for a team as well as creativity techniques used by artists and designers (Mateus-Berr, 2020).

The above theorists are part of the Constructivist school of educational theorists who base their theories around the scaffolding method of teaching where each concept of new learning is dependent on acquired knowledge and understanding of the previous step or concept. Interdisciplinarity has the benefit of merging diverse practices within each profession or skill to combine and use alternative theories to their own methods and in many instances create new ways of doing and new ways of thinking where the active participants become critical thinkers with shared knowledge and experience.

Kowalski, Lineweaver and Novak (2022) give several descriptions of interdisciplinarity in their efforts to develop a course design for integrative thinking for undergraduate students. They referenced Klein (1990) whose definition of interdisciplinarity is a more additive feature of a multidisciplinary approach to learning where higher order cognitive skills are required to understand the intertwined interactions between diverse perspectives. The authors give a direct quote from Dezure (1990) which describes interdisciplinary engagement as *'a process to construct knowledge in which students and instructors come together to analyse difference in disciplinary approaches to a problem and to work toward a synthesis – a new more comprehensive view than allowed by the vision of any one field'*.

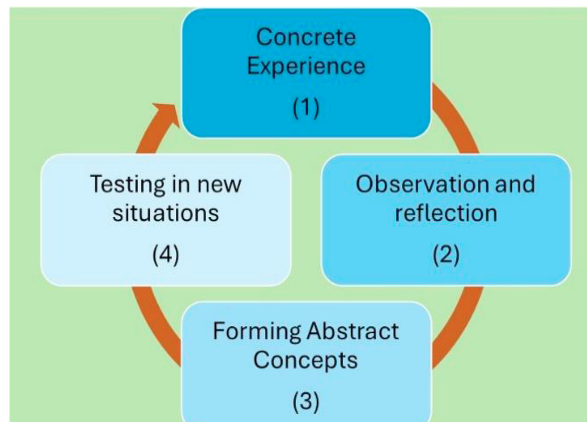

Figure 4. Adaptation of Kolb and Fry's Experiential Learning Model.

At the heart of all the methods shown above is the need for a fundamental *knowledge base* as a starting point. Engagement with interdisciplinary projects or objectives can be challenging from teaching *and* learning perspectives. However, the benefits of interdisciplinary projects have the potential to create an understanding of the techniques and regulations of diverse disciplines, arouse interest in previously unknown or diverse fields of study and understand the importance of socio-cultural collaboration to inform educational progress and create a world which accepts diversity and inclusivity amongst disciplines and people alike.

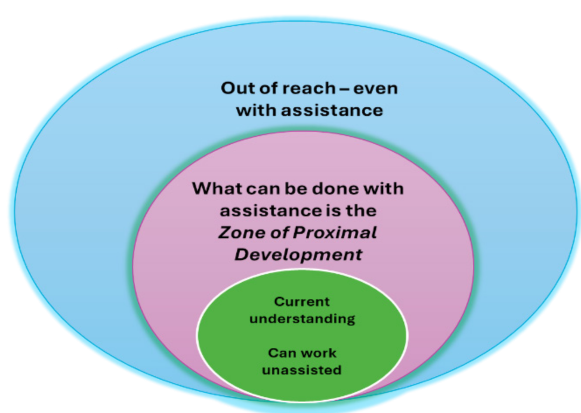

Figure 5. Adaptation of Lev Vygotsky's Zone of Proximal Development (Vygotsky, 1978).

Engineering education has many challenges ahead as the transformation of many industries moves from Industry 4.0 to Industry 5.0 which necessitates humans to interact on a more human-centred platform in industries with advanced technology and Artificial Intelligence (AI) robots. The need for 'critical thinking' and 'creative' forms of education, is now essential to educate and adapt a workforce with the skills to transform the many industries undergoing a paradigm shift in their processes. Industries such as communications, oil and gas, waste disposal and many more will benefit from the interdisciplinary educational projects underway in many universities and educational institutions with a view to creating the sustainability and conservation of our planet by interconnected disciplinary approaches to teaching and learning. The following is a descriptive example of course design, teaching engagement and student participation in a collaborative experiment combining art design, culinary skills and engineering principles to create a creative learning experience from an interdisciplinary perspective.

2.1 Course Design, Project Outline and Participants

The lecture-"Übersetzen II" serves as best practice example for interdisciplinary tertiary education in arts and engineering. Übersetzen II translates to "Translation II". The lecture is developed and led by Ruth Mateus-Berr. She is head of the Center for Didactics of Art and Interdisciplinary Education at the Institute of Studies in Art and Art Education. The lecture is a scientific seminar offering 4.0 ECTS credits over 2.0 semester hours (Uni-AK, 2023). This course, in collaboration with TU Wien, focuses on developing interdisciplinary teaching concepts around the theme of biomimetics. The primary research question it addresses is: How can interdisciplinary teaching concepts on the topic of biomimetics be developed? And subsequently be translated into secondary education? The objective of this course is to create an interdisciplinary/cross-curricular teaching concept on biomimetics. This is achieved through a collaboration between the University of Applied Arts Vienna/Mateus-Berr, an artist and art educator, specialized in interdisciplinary art and design education, and TU Wien/Gebeshuber. Ille C. Gebeshuber, a physicist specialized in nanophysics and biomimetics, plays a significant role in this course. Biomimetics is the science of learning from organisms and systems of organisms for applications in the human domain, e.g., in engineering, architecture and economy. As the Centre for Biomimetics at the University of Reading defines it, biomimetics is the abstraction of good design from Nature.

The course aligns with the curriculum in acquiring subject-specific competencies in art and design as well as technology and design, and also in developing interdisciplinary competencies in the education area of nature and technology, creativity and design, and environmental education for sustainable development.

The course emphasizes the importance of understanding natural and technological phenomena, fostering decision-making and action-taking abilities and encouraging students to engage with ethical questions related to nature, technology, humanity and the environment. It also aims to enhance students' creativity and ability to express themselves, promoting individual growth and community engagement through creative work. The course is mandatory in conjunction with the subject-related internship at schools and the supervision of students of the University of Applied Arts (Uni-AK). The final report of the students taking this class includes developing a research question, documenting one's artistic work, presenting the teaching project in the seminar, implementing it in schools, evaluating students' work, developing exam questions on the topic and reflecting on interdisciplinary collaboration. The approach taken at the University of Applied Arts Course shall be exemplified by three projects outlined in detail in the sections below: *Rainbow Cocoa Creations*, *EduFungi Constructs* and *Viral Canvas*. These projects were realized after introduction to interdisciplinary work and biomimetics by RMB and ICG, and the whole design process was supervised by the same.

3. RAINBOW COCOA CREATIONS

3.1 Project Overview

Rainbow Cocoa Creations is an engaging and innovative project that introduces pupils to the fascinating world of structural colours through a hands-on activity that combines science, art and culinary skills. The project is designed by engineering students from the TU Wien and technology and designs students from the university of applied Arts. The design process is supervised by two professors (ICG and RMB), from the arts and engineering fields.

By transferring rainbow colours from compact discs (CDs) onto chocolate (Fig. 1), pupils not only learn about the scientific principles behind structural colours but also experience the joy of creating and consuming their own beautifully structurally coloured chocolates. This project serves as a creative platform to explore material functionalities, the importance of structure in coloration and the art of making impressions. In addition, students will learn what nanostructures are and how their potential can be conveyed in the classroom.

3.2 Understanding Structural Colours

Structural colours result from the physical structure of a surface (Gebeshuber and Lee, 2015). These colours are produced by the interaction of light with micro- and nanostructures that cause scattering, reflection or interference of light waves. This phenomenon is responsible for the vibrant colours seen in living Nature, such as the iridescent hues of certain butterfly wings or on peacock feathers. In this project, the microstructures on the surface of compact discs, which act as diffraction gratings and create the rainbow patterns, serve as the basis for exploring structural colours.

3.3 The Process

Preparation. The project begins with the collection of unwanted CDs.

Transferring Colours. The pupils carefully remove the reflective layer of the CD, which exposes the microstructures responsible for creating the rainbow effect. This surface is then pressed onto heated chocolate, transferring the intricate patterns and thereby also the colours.

This process not only demonstrates the principle of making impressions but also shows how structural colours can be transferred between surfaces. Throughout the activity, students learn about the science behind structural colours and the importance of material structure in determining functionality. They also develop skills in working with their hands and experience the satisfaction of creating something beautiful and edible. After admiring their work, students can enjoy eating the chocolates, adding a delightful conclusion to the educational experience. This aspect of the project emphasizes the joy of learning by doing and the pleasure of creating something that appeals to the senses. This project offers a multidisciplinary learning experience, combining elements of physics (light and colour theory), biology (structural colours in Nature), art (creating patterns and designs, pattern recognition) and culinary arts (working with chocolate). Pupils gain a deeper understanding of how structure can influence material properties and functionalities, such as colour. They also learn the value of hands-on experimentation and the creative application of scientific principles. By engaging in this project, pupils not only acquire knowledge about structural colours but also develop practical skills and an appreciation for the intersection of science, art and culinary practices. The project fosters creativity, curiosity and a sense of accomplishment, making it a valuable addition to any educational curriculum focused on interdisciplinary learning and the application of science in everyday life.

4. EDUFUNGI CONSTRUCTS

4.1 Project Overview

In the project *EduFungi Constructs* the engineering and applied art students who aspire to become technology and design teachers focus in their four hours of subject-related internship at schools on the development of sustainable bricks made from mycelium. The core idea is to cultivate these bricks within an educational setting, allowing pupils to actively participate in the growth process. After the cultivation phase, the project transitions into a construction phase: pupils assemble the mycelium bricks to create a larger structure. Such an hands-on approach educates students about sustainable building materials and involves them in a practical application of these concepts, fostering a deeper understanding and appreciation for sustainable design and technology.

4.2 The Science Behind Mycelium Bricks and Technical Materials

Mycelium, the root-like structure of fungi, presents a biogenic material that can be harnessed to produce sustainable, biodegradable bricks (Nguyen et al, 2018). These bricks are grown by inoculating substrates with fungal spores and allowing the mycelium to colonize the substrate, binding it together into a solid form. Once fully colonized and dried, the material becomes lightweight, strong and insulative, making it an excellent candidate for sustainable construction (van Nieuwenhoven et al, submitted).

4.3 Advantages of Technical Materials not found in Nature

The project juxtaposes the natural, biogenic properties of mycelium with the advantages of technical, manufactured materials, highlighting a sustainable and integrated approach between the two. It offers the benefit of modular construction as a benefit not found in Nature: Use of standardized components in technical materials simplifies design and construction, allowing easy assembly and integration.

4.4 Implications for Future Research

The project underscores the importance of future research in materials science, particularly in understanding and mimicking Nature's methods of utilizing local resources sustainably (van Nieuwenhoven et al, 2023). This approach emphasizes the need for materials research to incorporate considerations of locality, recycling and waste management, aiming to address the environmental challenges posed by current engineering practices. In addition, this project not only provides a practical educational experience for future teachers and their pupils in their subject-related internship at schools but also serves as a model for sustainable construction and material use. It bridges the gap between the natural advantages of biogenic materials like mycelium and the technical benefits of manufactured materials, advocating for a holistic, integrated approach to sustainable development.

5. VIRAL CANVAS: EXPLORING DYNAMIC SURFACES

The aim is to observe virus surfaces. Pupils draw pictures of the surfaces, which change over time. The collection of pictures creates a larger image with altered surfaces.

The teacher introduced viruses and their different geometric and symmetric shapes during the lesson. First of all, the students were asked to create pulled string painting pictures and discuss how and why a change in surface shapes could occur, using examples like scanning electron microscope (SEM) pictures as inspiration. Thereafter the created pictures were summed up and put down together. To create an animation of the virus surface they use the method of a stop-motion video. After that the pupils can see the possible change of the surfaces they produce. Additionally to teaching students about the biological aspects of viruses, the project provides them a new physical viewpoint. This allows them to develop new mindsets and to gain design skills, for example. Of particular importance are the rapid and dynamic changes in viruses and their surfaces. This information can serve as a reference point for future technical issues.

6. CONCLUSIONS

In conclusion, the interdisciplinary approaches discussed in this paper underscore the transformative potential inherent at the intersection of artistic expression and scientific inquiry. By integrating the arts with engineering education, students are equipped with a versatile skill set that fosters innovation, adaptability and effective problem-solving abilities. Through the exploration of best practice examples in teaching and research, it is evident that interdisciplinary education not only narrows educational gaps but also enhances skill development in a rapidly evolving world. It is essential to rethink the approach of education and embrace interdisciplinary collaboration to enable engineers to solve today's problems and develop innovative solutions (van den Beemt et al., 2020). Collaboration between art and science is essential in the face of new challenges. Artists can provide engineers with new ways of thinking and helping them to see complex relationships beyond their own expertise. Pupils or engineers are allowed to use unconventional methods and look at a new point of view. In summary, it is important to understand that networked and interdisciplinary thinking can be particularly helpful in the field of automation and control. This requires basic and early education in schools. It allows different research disciplines to understand the nature of interdisciplinary work and to co-operate.

The examples presented, such as Rainbow Cocoa Creations and EduFungi Constructs, demonstrate the power of multidisciplinary learning experiences in fostering creativity, curiosity and practical skills among students. These projects not only deepen understanding of scientific principles but also create an appreciation for the combined qualities of science, art and technology in everyday life. Moreover, initiatives like the 'Übersetzen II' lecture and the 'Viral Canvas' project highlight the importance of interdisciplinary collaboration in addressing complex challenges. By bridging the gap between art and science, these projects encourage innovative thinking and provide new perspectives on societal issues, ultimately preparing students to become effective problem-solvers and innovators in a rapidly changing world.

In essence, the integration of arts education into engineering education not only enhances students' academic and professional development but also promotes inclusivity, diversity and sustainability in education and innovation. Moving forward, embracing interdisciplinary approaches will be crucial in preparing young minds to tackle the complex challenges of tomorrow and contribute meaningfully to the advancement of knowledge and society.

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