Chapter # 31

INNOVATIVE EDUCATION AND LIFE CYCLE ASSESSMENT OF 3D PRINTED PRODUCTS

Tetjana Tomášková, Daniel Duda, Jan Krotký, & Jarmila Honzíková
University of West Bohemia, Czech Republic

ABSTRACT
The chapter is devoted to life cycle assessment, specifically determining the carbon footprint of a product produced with the help of a 3D printer. At the beginning of the chapter, mind maps are described that relate to a specific product printed on a 3D printer, which has clearly defined goals: to describe the individual phases of the product's life cycle; orientate yourself in concepts related to product quality; define product life cycle costs; assess the impact of various factors on product quality; to evaluate the impact of production using a 3D printer on the environment. There are various calculators for calculating emissions, which, after filling in, will evaluate the result. However, it is often impossible to look at how the process was calculated to know how a particular value arrived at. Calculations were calculated in Microsoft Excel, where clear methods of calculation were presented to the students. At the end of the chapter, there are recommendations for applying the sustainable development of active learning methods to teaching.

Keywords: life cycle assessment, production process diagram, 3D printing, product quality, active learning methods.

1. INTRODUCTION

Sustainable development and environmental management make it possible to satisfy the needs of the human population and, at the same time, do not threaten the standard of living of future generations while preserving the intact ecosystem of our planet. Environmental management is a comprehensive approach to managing and minimizing the impact of human activities on the environment. It includes the various processes, tools and strategies that organizations use to achieve sustainability and environmental protection. Here are some key aspects of environmental management:

i. **Environmental Management Systems (EMS):** These systems, such as ISO 14001 and ISO 50001, help industrial companies systematically improve their environmental performance and improve energy efficiency. EMS includes the planning, implementation, control and continuous improvement of environmental policies and procedures.
ii. **Identification and evaluation of environmental aspects:** Industrial companies must identify and evaluate their environmental aspects, which are elements of their activities, products or services that may have an impact on the environment. This includes, for example, energy consumption, waste production and emissions.
iii. **Planning and implementation of measures:** Based on the identified aspects, industrial companies plan and implement measures to minimize negative

impacts on the environment. This can include energy savings, recycling, emissions reduction and other green initiatives.

iv. **Monitoring and measurement:** Industrial companies must regularly monitor and measure their environmental performance to ensure that their measures are effective and that they are achieving their objectives.

v. **Employee training and involvement:** A key part of environmental management is employee training and involvement in environmental initiatives. This includes raising awareness of environmental issues and promoting sustainable behaviour in the workplace.

vi. **Certification and audits:** Industrial companies can obtain certification of their environmental management systems through independent audits that verify that they meet the requirements of standards such as ISO 14001.

vii. **Life Cycle Assessment (LCA)**: One part of the environmental management is LCA. LCA is a system analysis focused on collecting and evaluating inputs, outputs, and possible impacts of a product (or service) on the environment during the entire life cycle. During the assessment, all impacts associated with the product are mapped, from the extraction of raw materials, production, and use to the end of the product's useful life and disposal.

Thus, environmental management is made up of a wide range of rules, activities and processes, including a number of documents, all of which help organizations and manufacturing companies manage their impacts on the environment and thus contribute to sustainable development and the future. If environmental management can be introduced to schools, it will play an irreplaceable role in education for sustainable development and environmental education in schools. The key question is how to approach the teaching of sustainable development in schools and how to familiarize pupils with the topic. In addition to basic information about the reasons for the emergence of the idea of sustainable development, its application in specific practical areas is also extremely important. The concept of education has a great advantage for sustainable development and aims to ensure the effectiveness of educational activities and maximum adaptation to the needs of both individual students and society as a whole, using current educational content and connecting it with extracurricular activities or everyday life (Mwendwa, 2017; Hernández-Diaz, Polanco, Escobar-Sierra, & Leal Filho, 2021); Fekih Zguir, Dubis & Koç, 2022). Another important aspect of education for sustainable development is maximum student involvement. 3D printing is generally recognized as an effective and sustainable technology, and in recent years, considerable research and development has taken place, including technological innovations in industrial enterprises to support 3D printing for better production processes and its activities (Zhichao, Qiuhong, Zhang, Tao & Zhang, 2016; Krotký, Honzíková, & Moc, 2016; Böhm et al., 2023). 3D printing technology can be applied, for example, in civil construction, mechanical engineering, electrical engineering, medicine, education, art, and confectionery. 3D printing has a significant impact on the environment; for example, this technology can reduce the amount of waste, as additive manufacturing produces less waste than traditional methods, which often involve cutting material. Among the advantages of 3D printing is the increasing use of recycled materials, which leads to a reduction in the consumption of new raw materials. The possibility of local production is another advantage, which leads to a reduction in logistics and transport costs and, thus, a reduction in the associated carbon footprint. The use of 3D printing in education at secondary vocational schools can have its advantages and disadvantages. Gaining practical skills in the areas of design, modelling, calculation, and production is one of the advantages that can increase the competitiveness of secondary school students in the labour market or allow them to more easily participate in university projects as part of their studies at universities. The knowledge gained in 3D printing can be used in various subjects, from mathematics and physics to art, which can also support students' creativity and innovative thinking, which is another advantage of 3D technology (Bull et al., 2010; Ford & Minshall, 2019; Assante, Cennamo, & Placidi, 2020). However, there are also challenges that need to be overcome, such as the lack the high financial costs of purchasing, operating and maintaining 3D printers. Research on 3D printing in Korea shows that teachers in both undergraduate and pre-service education lack the digital literacy and confidence needed to teach 3D printing technology, identifies the scope of knowledge required for teacher qualification, and defines steps for integrating 3D printing technology into individual classrooms (Song, 2018). The lack of methodology for the effective implementation of 3D printing in education at secondary vocational schools can be another obstacle that needs to be overcome. An online questionnaire study was conducted with teachers in Germany who had varying experiences with 3D printing technology, where almost half of teachers have 3D printers in their schools, while their use is even less widespread (Thyssen & Meier, 2023). The use of 3D printing is being applied worldwide, for example, in an Australian secondary school, an ethnographic study was conducted, where an analysis of the curricular activity was carried out from three different perspectives: the facilities involved in the project, the social and educational contexts, and the activities during the project implementation. Based on the evaluation of the results, it was highlighted how complex and complicated it is to implement the technologies in school contexts, especially the ways in technical and/or pedagogical innovations associated with 3D printing are possible (Nemorin, & Selwyn, 2016).

This contribution demonstrates the impact of 3D printing on the environment, leading to an understanding of the issues surrounding 3D printing while providing researchers and educators with better guidance for future research.

2. EDUCATION FOR SUSTAINABLE DEVELOPMENT

Education for Sustainable Development (ESD) is an important and key tool for building a more sustainable future, not only in educational institutions such as universities and secondary schools. The educational process must focus on developing the values and attitudes needed to address global challenges such as climate change, starting from primary schools. The goals of ESD, which are closely linked to the 17 Sustainable Development Goals (SDGs), are to empower individuals to make informed decisions and take responsible actions for environmental integrity, economic viability and a just society, both for current and future generations (United Nations, 2024, Transforming our world: the 2030 Agenda for Sustainable Development). Integrating sustainability into education involves including topics such as climate change, sustainable agriculture, renewable energy sources, and nature conservation in the school curriculum (Thürer, Tomašević, Stevenson, Qu, & Huisingh, 2018; Fekih Zguir et al., 2022). This approach also connects different subjects and disciplines so that students understand the complexity and interconnectedness of global problems. It is important to mention holistic learning here, which supports the cognitive, socio-emotional and behavioral dimensions of education, and this includes, for example, the development of critical thinking, analytical skills and the ability to analyze and solve problems (Hernández-Diaz et al., 2021). Education for sustainable development also connects different subjects within a discipline but also connects individual programs, and promotes cooperation and respect for different cultures and opinions, which can also lead to lasting sustainable development (Mwendwa, 2017). Lifelong learning is not limited to formal (e.g. schools, universities, educational institutions) education but extends to non-formal (e.g. projects, workshops, public campaigns) and informal education. Informal education then refers to learning from everyday experiences, media and social networks. ESD is crucial for the future of our planet and society (Tasdemir & Gazo, 2020). This concept of education for sustainable development includes four main areas such as economic, environmental, social and cultural (see Table 1), and each of these areas brings unique insights and methods to education.

Table 1.
Education for Sustainable Development (ESD).

Nr.:	Perspective	Goals	Methods
1.	Economic	Understanding basic economic principles; Promoting sustainable business and innovation; Supporting fair trade and economic justice;	**Entrepreneurship projects**: Students can create their own business plans focused on sustainability, such as eco-friendly products or services. **Case study analysis:** Students can study successful examples of sustainable businesses and discuss their strategies. **Economic scenario simulations:** Through simulations, students can understand the impacts of various economic decisions on the environment and society.
2.	Environmental	Raising awareness about nature conservation; Promoting sustainable use of natural resources; Reducing the ecological footprint of individuals and communities;	**Field research**: Students can conduct research in nature, such as monitoring biodiversity or water quality. **Ecological projects**: Schools can organize projects focused on recycling, composting, or creating school gardens. **Recycling and upcycling**: Students can create artworks or useful items from recycled materials.
3	Social	Promoting social justice and equality; Strengthening community development and cooperation. Raising awareness about human rights and social issues.	**Discussions and debates:** Students can discuss current social issues and seek solutions. **Volunteer activities:** Engaging students in volunteer activities in local communities, such as helping in charitable organizations. **Collaboration with local communities:** Projects that connect schools with local communities, such as workshops.
4	Cultural	Promoting respect for different cultures and traditions; Preserving and celebrating cultural heritage; Supporting intercultural understanding and dialogue.	Cultural exchanges: Organizing exchange programs or virtual meetings with students from other countries. **Study of world cultures:** Including the study of various cultures in the curriculum. **Art projects:** Creating artworks inspired by different cultures and traditions.

A comprehensive approach to education for sustainable development helps secondary vocational school students develop the skills and knowledge necessary to address global environmental challenges and also helps students better understand complex problems and seek new solutions.

The first phase is the concept and development, beginning with the initial idea and its implementation from prototype to serial form. It involves the compilation of various ideas and information and their gradual incorporation into a new product, followed by testing, market launch and marketing. The next phase is the growth phase, which involves the launch of product sales when the product gains popularity and increases market share. This phase can be described as the beginning of revenue compared to the development phase. After growth comes the maturity phase, where the growth of the market itself stops. This period is the period of the highest return on the product, when sales peak and stabilize, including cost optimization. This is followed by the decline phase, when interest in the product decreases, for example, due to new technologies or changes in customer requirements. The decision to withdraw a product from the market is a complex task. The last phase is disposal when the product is safely disposed of or recycled. Each of these phases has specific approaches and contains a series of calculations and analyses that can be used to plan for the success of the product and to maximize its lifespan, including financial profit.

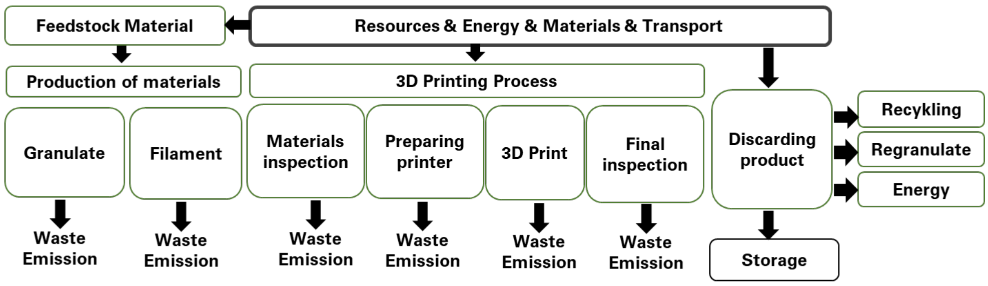
Costs are also related to product life cycle and sustainable development, and it is very important to familiarize students with this. Life cycle costs are total (cumulative) and can be divided into acquisition costs (for example, market research, project design and management, software development), ownership costs (for example, production planning, quality management, maintenance of production equipment, modernization, employee training), costs for disposal (for example collection and processing of non-functional products, legal fees (Ans & Koç, 2023; Bertini, Buehler, Halbheer & Lehmann. 2022).

2.1. Life Cycle Assessment of a Product From a 3D Printer

3D printing begins by creating a model of an object on a computer. One way is to create the model manually using a CAD (Computer Assisted Design) application or other 3D modelling software, and an alternative is to create a digital model by scanning the actual object with a 3D scanner. In general, there are three categories of 3D printing: selective binding, selective solidification, and selective deposition. The most commonly used technologies are usually called SLS (selective laser sintering), SLA (stereolithography), DLP (digital light processing), FDM (fused deposition modelling), or FFF (fused filament fabrication). Given the current trend of linking teaching with practice, the use of printers for educational purposes appears to be a very suitable tool for teaching, especially technical subjects. 3D printing technologies are a field that is very promising in itself today, as they find their application in various sectors, within which many companies use it as the main production equipment and allow the creation of complex geometries that would be difficult or impossible to produce using traditional methods, thereby reducing waste (Zhichao et al., 2016).

But even for 3D printing, an environmental analysis is necessary. It is interesting to study that home 3D printing produces minimal waste, reducing its environmental impact. Home 3D printing reduces transportation needs, including packaging, which means less plastic (Drizo & Pegna, 2016). That's why we used a home 3D printer (Prusa MK2.5 3D printer located in the university laboratory) to calculate the Life cycle assessment of a product.

Figure 1.
Scheme of the production process of 3D printing



2.2. Creation of a Carbon Footprint Calculator

Choosing the right emission factors is the key to correctly calculating the carbon footprint, but unfortunately, it is not always easy to calculate. Emission factors represent the amount of greenhouse gas emissions per unit of activity or quantity, and their correct selection depends on data sources, specificity, and geographic location. Determining the boundaries of analysis is a key initial step for any carbon footprint analysis. There are three main approaches: organizational boundaries, operational boundaries, and system boundaries. These limits determine what emissions will be included in the calculation. Practical steps include identifying emission sources, collecting data and applying emission factors. It is also important to check and validate the calculations, ideally through an external audit. The following stages were chosen to determine the product's greenhouse gas emissions using 3D printing: material transportation, production of Polyethylene terephthalate (PET) material granules, energy consumed for printing, and material recycling PET. It means determining which steps of the production process (Figure 1) are included in the calculation of greenhouse gas emissions and which are not.

2.2.1. Material Transportation

Emissions arise during the transportation of raw materials to the production plant. This includes fuel consumption and CO_2 emissions from vehicles.

Calculation of CO_2 emissions for 1 litre of diesel fuel: 1,92 kg of oxygen is needed to burn 1 litre of diesel fuel (0,84 kg); the resulting carbon dioxide is equal to the sum of 0,72 kg of carbon and 1,92 kg of oxygen, which is 2,64 kg of CO_2 from 1 litre of diesel fuel burned (Baťhová, 2021). The amount of carbon dioxide that a vehicle emits into the air is directly proportional to the amount of fuel it consumes and the carbon content of the given type of fuel. PET material is produced from oil and natural gas, which we import, for example, from Saudi Arabia (Hamieh et al., 2022). The road distance between the Czech Republic and Saudi Arabia was considered to be 5295 km. The total fuel consumption of diesel fuel is 371 litres.

2.2.2. Production of Polyethylene Terephthalate (PET) Material Granules

The production of PET granules begins with the raw materials, which are ethylene glycol and terephthalic acid or dimethyl terephthalate. These raw materials are derived from petroleum and natural gas. The production process starts with polymerization. This process occurs in two main steps: esterification and polycondensation. The resulting PET polymer is then melted and passed through an extruder, where it is formed into long fibres. These fibres are then cooled and cut into small granules. Finally, the PET granules are dried and conditioned to remove moisture and improve their processability for subsequent 3D printing.

Consumption of basic raw materials to produce 1 kg of PET granulate: oil 0,64 kg (33,18 MJ) and natural gas 0,23 kg (12,63 MJ) and CO_2 in the production of 1 kg of PET granulate is 2,3 kg (Přibylová, 2000).

2.2.3. Energy Consumed for Printing

The university's laboratory carried out calculating CO_2 emissions related to the printing process and energy consumption per 1 kg of product. Prusa MK2.5 3D printer was used to print the product. Consumption for preheating the pad and nozzle was 11 Wh (40 kJ). Energy 93 Wh (335 kJ) was used to print a product weighing 4,14 g. The energy to print 1 kg is 22,5 kWh (81 MJ). From the statistical data of the Ministry of Industry and Trade of the Czech Republic, the value of the CO_2 emission factor from public electricity production for the year 2022 was 0,413 t CO_2/MWh. When 1 MWh of electricity is produced in the Czech Republic, 413 kg of CO_2 is released (430 g of CO_2 is released when 1 kWh of electricity is produced).

2.2.4. Material Recycling PET

When calculating CO_2 for PET recycling, it was assumed that the combustion would take place in a high-quality incinerator, where a highly controlled combustion process would burn PET and produce carbon dioxide and water. The amount of CO_2 is calculated from the PET chemical formula: HO- [-CH_2 -CH_2 -O-OC- C_6H_4 -CO- O-] n -OH. Burning 1 kg of PET produces 2,2 kg of CO_2. In the case of incomplete combustion, other substances can be formed, which can also cause an increase in CO_2 values.

3. CONCLUSION

Elementary, secondary, and grammar schools and universities can effectively incorporate the concept of education for sustainable development (ESD) into their curricula, which will allow them to combine traditional teaching topics and newly integrate economic, social, environmental, and cultural elements. It is equally important to methodologically connect secondary school teaching with the real world. To achieve this, the method of locally embedded and situational learning, which is characteristic of ESD, is proposed. ESD implemented through projects where engaged learning and experiential pedagogy can be applied. Holistic integration of sustainable development across all subjects in secondary vocational schools, including community involvement and manufacturing industries, can improve learning outcomes. It can be stated that effective education for sustainable development also requires very well-trained teachers; therefore, individual personal professional development plans should be created that will allow teachers to grow professionally based on completing various training courses, workshops or participating in conferences. Student grading and assessment and its development is another aspect that needs to change in the context of sustainable development in secondary vocational schools, which means that traditional examinations may not be relevant, so alternative assessment methods should be considered, such as assessment based on personal projects.

Materials innovation is key to advancing 3D printing research, and this includes investigating product design and the properties of selected materials, which will require product and material analysis and subsequent assessment of factors and risks, such as storage conditions, manufacturing conditions, quality control, and data evaluation. It is also important to conduct a more thorough analysis of 3D printing-related CO_2 emissions, including specific case studies, which will provide insight into their overall environmental impact, including energy consumption during production and end-of-life disposal options. Innovations in the field of 3D printing should subsequently be reflected in teaching at universities and high schools.

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AUTHORS' INFORMATION

Full name: Tetjana Tomášková
Institutional affiliation: Faculty of Education, University of West Bohemia
Institutional address: Univerzitni 2732/8, 301 00 Pilsen, Czech Republic, Europe
Short biographical sketch: She received a master's degree in Electrical Engineering in 2012, and in 2017, she defended her work and earned a title Ph.D. in Electrical Engineering at the Department of Technologies and Measurement at the Faculty of Electrical Engineering at the University of West Bohemia in Pilsen, Czech Republic. Her main research interest is heat transfer in electrical insulation systems. She is engaged in modelling and numerical analysis. Other areas of interest are sustainable development, ecology and life environment. In addition to the scientific area, she was an employee of several manufacturing companies and made knowledge of the production processes and product quality settings (the person responsible for the organization of customer visits and audits from the compilation of the audit program to the resolution of corrective and preventive measures identified). She holds the international certificate Quality Management System - Head Auditor ISO 9001: 2015 with the International Exam.

Full name: Daniel Duda
Institutional affiliation: Faculty of Mechanical Engineering, University of West Bohemia
Institutional address: Univerzitni 2732/8, 301 00 Pilsen, Czech Republic, Europe
Short biographical sketch: He received his master's degree in Physics from the Faculty of Mathematics and Physics at Charles University in Prague (MFF UK) in 2013. In 2017, he defended his dissertation titled "Quantum turbulence in superfluid helium studied by particle tracking velocimetry visualization technique" and earned his Ph.D. in Physics. His main research interest lies in the study of quantum turbulence in superfluid helium, utilizing advanced visualization techniques. He is also engaged in the visualization of selected flows of superfluid helium using solid hydrogen tracer particles, a topic he explored during his master's studies. In addition to his academic pursuits, he has been a member of the European Mechanics Society (Euromech) since 2015, with personal number EM 140388, and the Union of Czech Mathematicians and Physicists (in Czech: Jednota Ceskych matematiku a fyziku (JCMF)) since 2016, with personal number 8304.

Full name: Jan Krotký
Institutional affiliation: Faculty of Education, University of West Bohemia
Institutional address: Univerzitni 2732/8, 301 00 Pilsen, Czech Republic, Europe
Short biographical sketch: In 2006, he obtained a master's degree at the Faculty of Education, University of West Bohemia in Pilsen, specializing in physics and didactic technologies. In 2015, he completed his doctoral studies at the same faculty and earned a Ph.D. in the field of Information and Communication Technologies in Education. He focuses on didactic technologies and is a principal investigator and co-investigator of several faculty and national projects. He is a co-author of textbooks for technical education at elementary schools and the author of numerous professional and scientific articles in domestic and international journals. Currently, he heads the Department of Mathematics, Physics, and Technical Education and serves as Vice-Dean for Education at the Faculty of Education, University of West Bohemia in Pilsen.

Full name: Jarmila Honzíková
Institutional affiliation: Faculty of Education, University of West Bohemia
Institutional address: Univerzitni 2732/8, 301 00 Pilsen, Czech Republic, Europe
Short biographical sketch: In 1981, she obtained a Master's degree in Teaching for Primary School at the Faculty of Education in Pilsen; in 1991, she passed the rigorous exams at the same faculty and obtained the degree of PaedDr. In 2001 she completed her doctoral studies in pedagogy at Charles University in Prague and obtained the degree of Ph.D. In 2004, she habilitated at Matej Bel University in Banska Bystrica (Slovakia) and received the title of Associate Professor. In 2018, she was inaugurated at Constantine the Philosopher University in Nitra (Slovakia) and was appointed professor by the President of the Republic. Her research work focuses on non-verbal creativity, psychomotor skills and popularization of technical education. The results of her work have been published in many articles in domestic and foreign journals and scientific and professional monographs. She is the author of 8 industrial designs registered at the Institute of Industrial Design.