A collaboration between:

ENERGI VAND

WindEurope

TEACHER'S TOOLKIT

Design, construct, and test wind turbine blades using Makerspace technology for lower secondary schools

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ABOUT THIS TOOLKIT

With this toolkit, we aim to teach lower secondary school students about wind energy whilst spurring their curiosity for the engineering design process and Makerspace technology. This project was developed by the Danish Science Center ENERGY & WATER and made possible through a partnership with WindEurope. Since 1999, ENERGY & WATER has been an environmental school and educational partnership between the City of Copenhagen and Greater Copenhagen Utility (HOFOR). ENERGY & WATER offers courses suitable to all grade-levels to schools in and around Copenhagen, each year receiving 23.000 pupils. The interactive learning environment at ENERGY & WATER focuses on utility, specifically on energy and water supply, climate change and climate adaptation, always from a sustainability perspective.

This curriculum was created as an addition to the existing wind energy teaching resources for primary-level education, also available through WindEurope. This teacher's toolkit evolved from an existing week-long course at ENERGY & WATER focusing on wind energy and wind turbine blade design. Knowledge and experiences from the course have been evaluated and expanded in this toolkit.

This toolkit links the subjects of **science/technology, mathematics, history, geography, physics, chemistry, biology, and engineering** with wind energy topics. It is designed to suit any school and any teacher that wishes to teach their students about wind energy. The teaching methods central to this curriculum is Technological Literacy, practical expertise, engineering and innovation. The curriculum can be carried out in the classroom, but a Makerspace is recommended.

Carrying out the modules in this curriculum does not require the teachers to have had any specialized training, although being familiar with basic Makerspace technology is an advantage. The curriculum can be carried out in full or parts of it can be taken out to fit with the student's learning objectives.

We hope you will enjoy the toolkit!

Figure 1: Students bending an acrylic rotor blade using a heat gun.

HOW TO USE THIS TOOLKIT: TEACHER'S GUIDE

This toolkit is an extension to the "Learning wind energy in primary schools" toolkit. This toolkit has three modules which can be completed consecutively or adapted depending on student and teacher needs:

- **Module 1:** Windmills, turbines, and their history
- **Module 2:** Materials
- **Module 3:** Aerodynamics

The structure of the modules follows the primary school toolkit and includes:

- A **Lesson Plan** showing the objectives for student learning in terms of knowledge and competences and the teaching activities. These objectives might help you prepare your own teaching.
- **Examples of student work** from testing the toolkit at ENERGY & WATER, so you can see what products and results might look like (they are in Danish, but they are only meant to give you an idea).

The modules include both individual and group projects and rely on Technological Literacy, practical expertise, and engineering and innovation.

The toolkit comes with a **Support Material** for the teacher which includes theoretical aspects, charts and further instructions. We recommend that teachers become familiar with the Support Material as they go through this toolkit.

The toolkit is designed to be used independently by the teacher in a Makerspace but without the need for any external expertise.

If you want more background knowledge on the topics covered in the toolkit, please find links to reliable information at the end of this document.

BACKGROUND KNOWLEDGE AND COMPETENCIES OF 7TH GRADE STUDENTS

Windmills and Wind Energy

- Familiar with basic parts of a **wind turbine: blades, hub, rotor, nacelle, gearbox, generator**, and **tower**
- Understand that **wind energy** is **renewable**

Mathematical Skills

- Familiar with **addition, subtraction, multiplication**, and **division** of decimal numbers, fractions, and percentages
- Can **create, interpret**, and **analyze graphs,** e.g. to represent **wind speed data, energy production rates**, and **comparisons** between energy sources
- Can measure **lengths, areas**, and **volumes** in various units
- Can calculate **surface areas** (m^2) and **volumes** (m^3)
- Can work with **angles**

Scientific and Physics Concepts

- Familiar with concepts of **energy** and **energy transformation**
- Familiar with concepts of **speed** and **velocity** and can apply these to real-life scenarios, such as **wind speed**
- Understands how the mechanical energy from the **windmill blades** is transferred through a **gearbox** to the **generator** to produce electricity
- Familiar with basic principles behind **wind formation** and how **weather patterns, temperature differences**, and **the rotation of the Earth** create global wind patterns
- Familiar with the relationship between **wind speed** and **energy production**

WHAT DID THE STUDENTS LEARN FROM THE FIRST TOOLKIT ON "LEARNING WIND ENERGY IN PRIMARY SCHOOLS"?

1. **Learning about energy**
   • Defining energy and energy types
   • Researching energy sources and presenting the research work
   • Learning about different aspects of wind energy: administrative, economic and environmental

2. **Constructing an anemometer and taking measurements**
   Constructing an anemometer
   • Using an anemometer to measure wind

• Performing experiments with the anemometer
• Measuring the circumference and area of the circle made by the anemometer

3. **Understanding wind turbine technology**
   • Assessing their knowledge about wind turbines
   • Learning about how wind turbines work
   • Building a wind turbine and testing it
   • Grammar lesson using new vocabulary

4. **Learning about wind**
   • Assessing student knowledge about wind
   • Putting together wind and aerodynamics experiments
   • Studying the global wind map and wind types
   • The history of wind
   • Studying the respiratory system

OVERVIEW OF MODULES AND ACTIVITIES

ACTIVITIES			
MODULE	**LESSON**	**SUBJECT**	**DURATION**
1. Windmills and their history	• Refresh how a windmill works and the importance of renewable energy • Learn about the history of windmills and turbines • Learn to laser cut / 3D-print, and build models	• Physics • History • Geography • Science/ Technology • Engineering	• One (50-minute) class to refresh knowledge on windmills and renewable energy • Two (50-minute) classes to research history of windmills and present a windmill type • Three (50-minute) classes to build and test a windmill type
2. Materials	• Introduce wind turbine materials, discussion, and creating posters/slides • Introduce environmental impacts of wind turbine production and future trends in the industry • Recycle and test bending strengths of materials	• Physics • Mathematics • Biology • Chemistry • Science/ Technology	• Two (50-minute) classes to introduce wind turbine materials, discussion, and creating a chart • One (50-minute) class on the environmental impacts of wind turbine production and future trends • Two (50-minutes) classes to recycle and test plastic
3. Aerodynamics	• Introduce aerodynamics and paper airplane testing • Design, build, test, and improve a wind turbine • Design poster and prepare group presentations of wind turbines • Group presentations on wind turbine-projects	• Physics • Mathematics • Biology • Chemistry • Science/ Technology • Engineering	• Two (50-minutes) classes to introduce aerodynamics and paper airplane testing • 5-10 (50-minutes) classes to design, build, test, and improve your own wind turbine, can be expanded (time) • One (50-minutes) class to design poster and prepare presentation of wind turbine • One (50-minutes) class for group presentations of self-made wind turbine

MODULE 1
WINDMILLS AND THEIR HISTORY

OVERVIEW

This module starts with a recap of what the students learned during the "learning wind energy in primary schools" toolkit, specifically how a windmill works and why renewable energy is important. The module also introduces the history of windmills, and the students work with different windmill types. The students are introduced to laser cutters/3D printers and will build different windmill types.

GRADES

7th-9th grade (13-15 yo)

DURATION

- One (50-minute) class to refresh how a windmill works and the importance of renewable energy
- Two (50-minute) classes to learn about the history of windmills
- Three (50-minute) classes to learn to laser cut/ 3D-print, and build models

SUBJECTS

- Physics
- History
- Geography
- Science/Technology
- Engineering

LEARNING OBJECTIVES

After this module, the students will have gained the following knowledge and competences:

Knowledge

- Understanding key differences between early windmills and modern wind turbines
- Understanding key considerations in wind energy history: Location, societal and cultural importance, global warming, and environmental impact

Competences

- To recognize the historical use of windmills to carry out tasks such as grain grinding, water pumping, and electricity generation
- To comprehend the technological advances in windmill production
- To analyze the social and environmental impact of wind energy throughout history
- To place the development of windmills and wind turbines in a historical context

MODULE 1
LESSON PLAN

MATERIALS

For windmill and turbine construction you will need:

- Laser cutter
- Acrylic sheets
- Vacuum former
- Wind machine
- Heat gun
- LEGO-set-9686
- LEGO-set-9688

METHOD

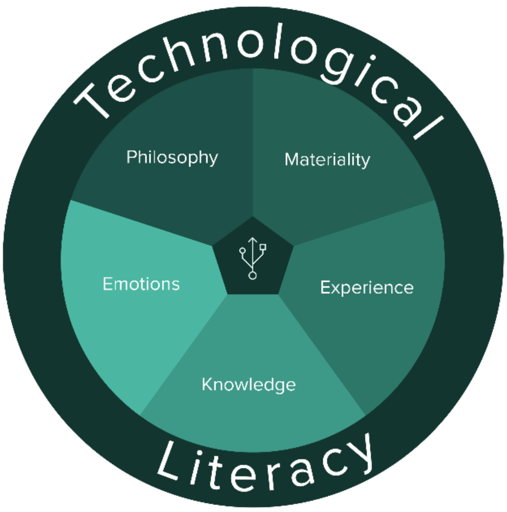


Figure 2: The Model for Technological Literacy

In this module the focus is on technological literacy (fig. 2), and we will be working with **the material**, **experience-based**, **knowledge**, **emotional**, and **the philosophical** aspects of wind energy. From **the material** aspect, we will be looking at, e.g., technology and dependence; how we, as people, are dependent on various technological systems. From the **experience-based** learning aspect, the students will, e.g., work with technology and design, designing and testing solutions. From the **knowledge** aspect, the students will learn about technology, society, and history; how technology influenced different societies at different historical periods. Furthermore, the students will be working on the **philosophical** aspects in the sense of technology and the future; looking at how technology shapes our society and future.

STEP 1

Refresh how a windmill works

- In the classroom, each student makes a drawing of a modern wind turbine with all the components they know (see fig. 3).
- The teacher asks a couple of students to present their wind turbine and explain how the turbines work.
- The students and the teacher summarize how the windmills work: "Wind makes the windmill blades spin, generating kinetic energy. The spinning blades will make the shaft in the nacelle turn, a generator in the nacelle converts the kinetic energy into electrical energy."

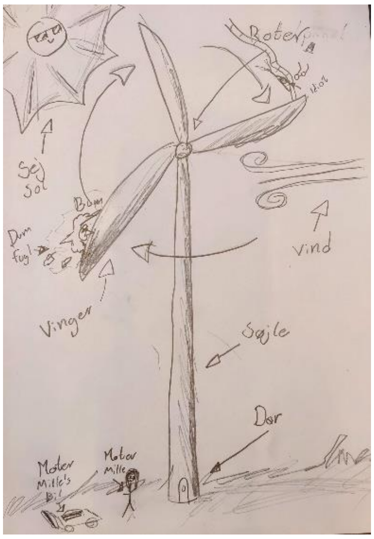


Figure 3: Example of student drawing of a modern wind turbine.

STEP 2

Renewable energy and fossil fuels

The students and teacher discuss the advantages and disadvantages of renewable energy and use of fossil fuels. Together they make the following table.

	Renewable Energy	Fossil Fuels
Pros	Clean Cheap to run Infinite Creates jobs Public health	Reliable Easy Cost reliable
Cons	Expensive to set up Availability Need for energy storage Geographic limitations	Creates pollution Will run out Public health

STEP 3

History of windmills

The teacher gives an overview of the evolution of windmills through history, from the first known vertical axis windmills (VAWT) of Persia to the modern horizontal wind turbines (HAWT). The students and teacher identify six windmill types for further research:

- Savonius Rotor (Persian Windmill) (VAWT)
- Darrieus Rotor (VAWT)
- Cup Anemometer (VAWT)
- American farm windmill (HAWT)
- Dutch Windmill (HAWT)
- Modern Wind Turbine (HAWT)

STEP 4

Present a windmill type

The students, in groups (4-5 students per group, 6 groups in total), pick one of six windmill types and answer the following questions regarding their windmill type. After answering the questions, the groups make a 1-page PowerPoint presentation (see fig. 4) with pictures and information about their windmill from which the groups present their windmill type.

- Where and when was it invented?
- For what was it used?
- What was its societal importance?
- What was its benefits?
- What was its drawbacks?
- Is it in use today? Why?

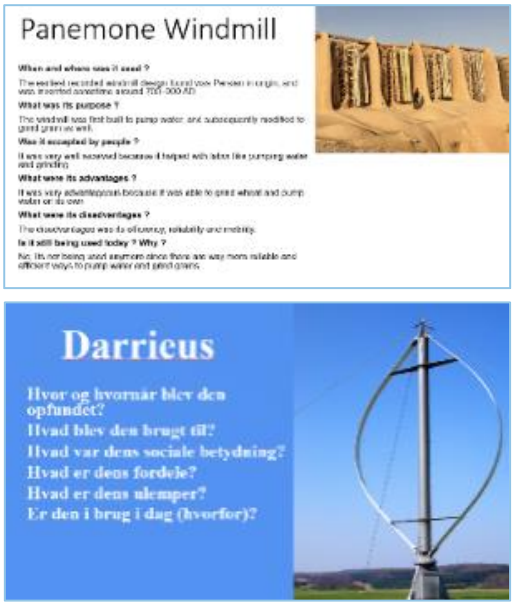


Figure 4: Example of student presentation of windmill types

STEP 5

Build and test your windmill type

The students, in the same groups as in step 4, construct wings for their windmill type and test its functionality (see procedure in the blue box below and the step-by-step guide in the Support Material). If the students are not yet familiar with the vacuum former, laser cutter and/or 3D printing-design program, then this exercise is a great opportunity to learn about the technologies.

Compare and discuss the different results in the class. Were you able to make the different windmills spin? Did you get the results that you expected? Etc.

Another option is to build the windmills using household objects, e.g., plastic bottles, cardboard, sticks, a fan etc. For further description and procedural details see the Support Material.

Alternatives to the LEGO sets are available, e.g., a bike generator connected to an ammeter.

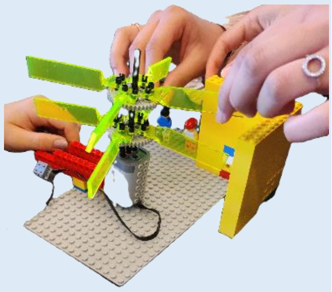
MAKERSPACE

Materials:

- Laser cutter, 3D-printer, heat gun, vacuum former, wind machine, LEGO-set-9686, and LEGO-set-9688, ready-to-use windmill towers

Procedure (construction):

- Design and cut the rotor blades on the laser cutter.
- Form and make cups (for the anemometer) with heat guns or on the vacuum former.



Procedure (test):

- Gather the students. Discuss how to test the efficiency and the scientific practice (where to place the windmills and the wind machine, length of tests, etc.)
- Test the efficiency of the windmills using the wind machine and the LEGO energy-meter.
- Discuss the efficiency of the different types of windmills/turbines. Why did we get the results we got?

Figure 5: Example of wind turbine which is ready for testing with the wind machine. The turbine is connected to an energy-meter.

MODULE 2
MATERIALS

OVERVIEW

This module introduces the challenges of selecting materials for wind turbine production. The students learn about both physical aspects and environmental impacts of various materials. Tests and calculations of the flexural strength is carried out and the students will evaluate and discuss which materials are preferred for wind turbine production.

GRADES

7th-9th grade (13-15 yo)

DURATION

- Two (50-minutes) classes to introduce wind turbine materials, discussion, and to create posters/slides
- One (50-minutes) class to introduce environmental impacts of wind turbine production and future trends in the industry
- Two (50-minutes) classes to recycle and test plastic

SUBJECTS

- Physics
- Mathematics
- Biology
- Chemistry
- Science/Technology

LEARNING OBJECTIVES

After this module, the students will gain the following knowledge and competences:

Knowledge

- Understanding the challenges of resource and material selection, both in the sense of lack of resources and end-of-life use of materials
- Understand the concept of flexural strength, how to test it, and the importance of the characteristics of the chosen materials for wind turbine production

Competences

- To assess materials based on strength, weight, durability, corrosion resistance, and aerodynamic properties
- To evaluate the sustainability of materials in wind energy, considering factors like recyclability and the importance of renewable materials
- To test and experiment with various materials, understanding how material choices affect turbine blade performance

MODULE 2
LESSON PLAN

MATERIALS

For recycling plastic and bending tests you'll need:

- Plastic caps (ask students to bring in)
- Flat plated panini grill
- Weights with hook
- Materials to test: Spaghetti, acrylic, HDPE (plastic caps)

METHOD

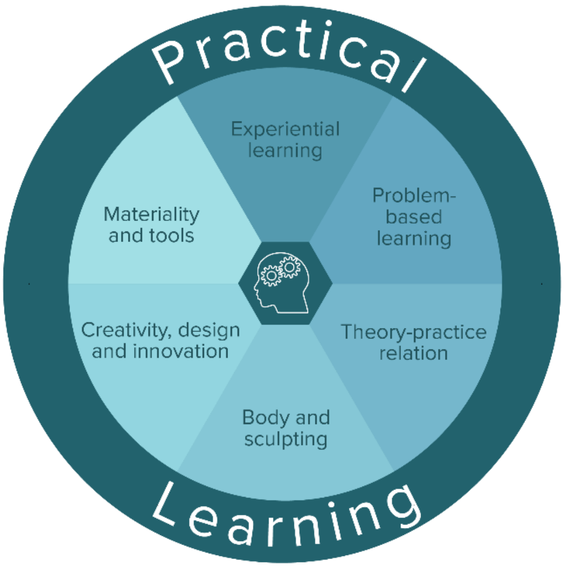


Figure 6: Model for practical learning.

Both student and teacher programs focus on developing practical skills, and therefore the Model for Practical Learning (fig. 6) is used to ensure that the various aspects of practical learning are included.

In this module the students will combine theoretical learning with practical exercises. They will learn about different aspects and characteristics of various materials. Afterwards, they will develop hypotheses and test the bending capabilities of materials. The students will also learn about future trends in wind turbine production and design their own futuristic wind turbine considering production and materials.

STEP 1

Materials for rotor blades and wind turbine towers

The teacher introduces the following six materials which are commonly used in wind turbine production.

Rotor blade materials:

- Fiberglass: Durable and lightweight, but energy-intensive to produce
- Carbon Fiber: Stronger and lighter than fiberglass. Very expensive and difficult to recycle
- Wood: Renewable and easier to recycle but less durable

Wind turbine tower materials:

- Steel: Strong and widely used but has a high carbon footprint
- Cement: Very stable and cost-effective but has a high environmental impact

- Concrete: Most widely used material for construction. 90% of the carbon footprint in concrete stems from the production of cement.

STEP 2

Material-poster/slide

In groups, the students discuss and investigate the cost, durability, and environmental impacts of one of the materials used for rotor blades and towers. The students create a poster or slide (see fig. 7), informing the other student of the cost, durability, and environmental impact of materials for rotor blades and wind turbine towers.

Figure 7: Examples of student slides on materials

STEP 3

Discussion: which is the best material?

Together with the teacher, the students gather the costs and environmental impact (CO_2-emissions) of the different materials in a table.

The students then discuss which materials might be best for wind turbine production (blades, and towers) considering costs and environmental impact and which parts ideally could be improved upon or changed.

STEP 4

Environmental impact of wind turbine production

The teacher introduces environmental impacts of wind turbine production, reusability and end-of-life use of the materials. The students research the future trends in wind turbine production, with a focus on emerging materials such as bio-composites, advances in recycling materials, 3D-printed materials and future technological innovations of wind turbines.

STEP 5

Design a future wind turbine

- In groups, the students design a future wind turbine (see fig. 8) using new materials and the technological innovations previously discussed.

STEP 6

Presenting the design of a future wind turbine

- Each group makes a 1-page PowerPoint presentation with their design and material considerations and present their design to the rest of the class.

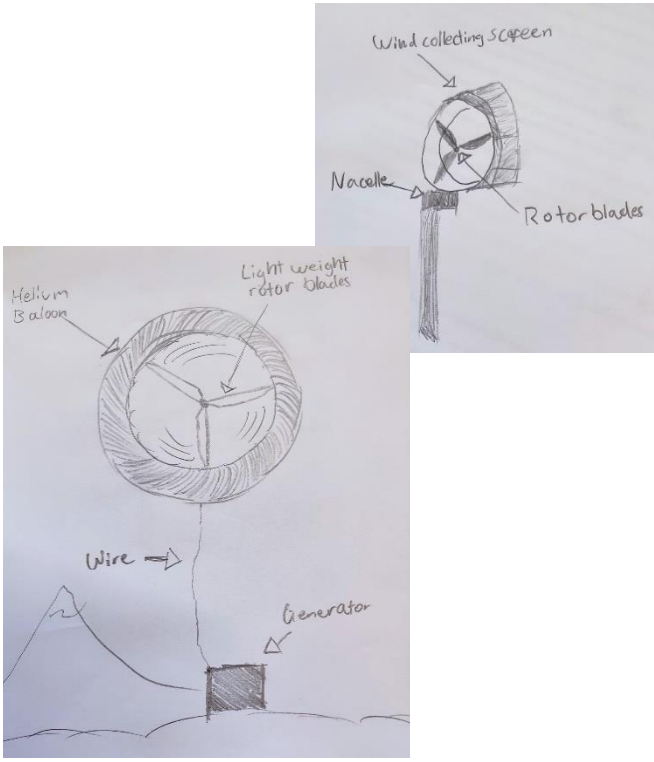


Figure 8: Examples of student designs of future wind turbines

STEP 7: STRENGTH EXPERIMENT

Recycling plastic

To highlight challenges in recycling materials for reuse, the teacher and students recycle plastic and test the material to compare it with "new" plastic. Though not used in wind turbine production, HDPE is ideal for classroom-recycling purposes.

The students bring in bottlecaps to recycle the plastic (HDPE, type 2). Together with the teacher, the students heat up the bottlecaps on a two-sided flat plate panini press until the caps are melted together (see fig. 9).

The fused plastic is then left overnight to cool. See detailed procedure and safety measures in the Supporting Material.

Figure 9: Plastic caps are heated and melted for recycling purposes

Compare the strength of different materials

The teacher prepares plastic sticks for tests: Once cooled, the recycled HDPE can be cut into 1x25cm pieces, e.g. using a laser cutter. If there is enough recycled plastic, then each student group should preferably receive one stick. Cut a small round hole in one end of the stick to attach hanging weights for cantilever bending tests. New HDPE sticks (from acrylic sheets) are prepared similarly.

Using the edge of a table, fasten one end of the stick whilst the other end hangs off the table (see fig. 10, and the Support Material). The students hang different weights on the recycled and new HDPE sticks to find and compare their breaking points. Different amounts of hard spaghetti bundles can also be tested for comparison. The students fill in a table like the table shown below.

Discuss in the class, whether this test posed any challenges in working with recycled materials (strength, aesthetics, reusability of different plastics etc.).

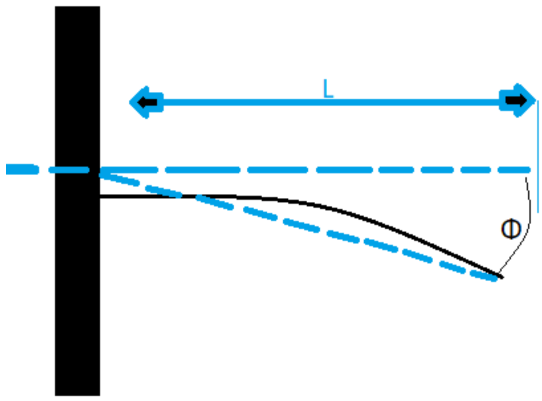


Figure 10: Simple illustration of the setup for cantilever bending tests

Cantilever bending test				
Material	Spaghetti (50g)	Spaghetti (100g)	HDPE (Acrylic)	Recycled HDPE
Breaking point (g)				

MODULE 3
AERODYNAMICS

OVERVIEW

This module introduces the students to the concept of aerodynamics. Through hands-on tests, the students will learn about the importance and utilization of aerodynamics in rotor blade production. In groups, the students will use this knowledge to design, build, test, and improve their own wind turbines using engineering and innovation methods. The students will summarize their group project designs and results on a poster from which they will present their wind turbines to the rest of the class.

GRADES

7th-9th grade (13-15 yo)

DURATION

- Two (50-minutes) classes to introduce aerodynamics and paper airplane testing
- Five-Ten (50-minutes) classes to design, build, test, and improve own wind turbines. This section can be expanded timewise
- One (50-minutes) class to design a poster and prepare a presentation of their wind turbine project
- One (50-minutes) class for group presentations of their wind turbine projects

SUBJECTS

- Physics
- Mathematics
- Science/Technology
- Engineering

LEARNING OBJECTIVES

After this module, the students will have gained the following knowledge and competences:

Knowledge

- Fundamentals of aerodynamics
- Methods of propulsion
- Effect of aerodynamic designs
- Calculate total wind force using the Pythagorean theorem.

Competences

- To understand the basic principles of aerodynamics
- To apply aerodynamic principles to optimize the shape and size of blades
- To test their rotor blade designs, collecting, and analyzing data
- To iterate and refine their rotor blade designs based on testing feedback, improving the blade angles, shapes, and materials
- To approach engineering problems methodically

MODULE 3
LESSON PLAN

MATERIALS

For wind turbine production you will need:

- Laser cutter
- Acrylic sheets
- Wind machine
- Acrylic bending machine or heat gun
- Heat resistant gloves
- LEGO-set-9686
- LEGO-set-9688

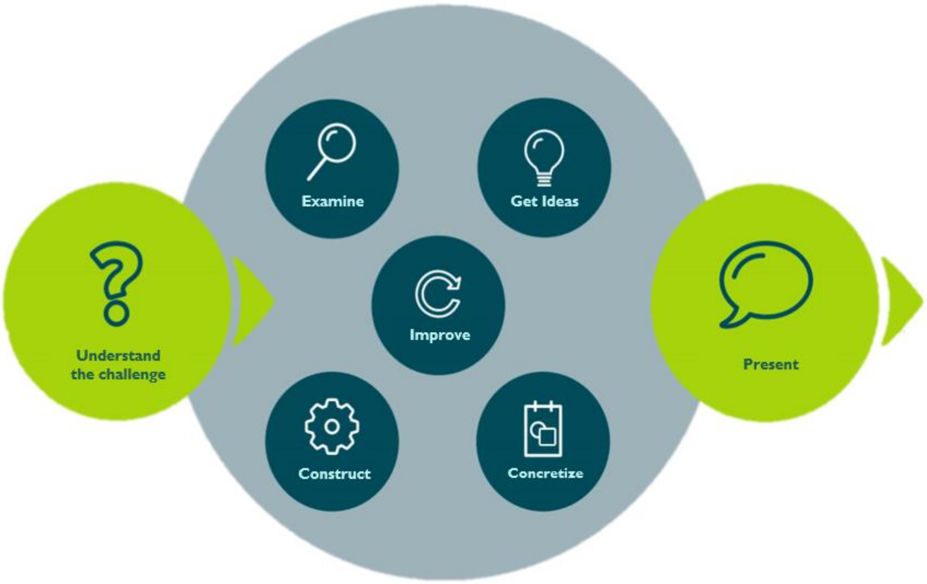


Figure 9: The Engineering Model

METHOD

Our makerspace approach follows the engineering design process (see fig. 9 for the Engineering Model), where students develop practical skills by turning ideas into prototypes that are continuously tested, evaluated, and improved. The model supports competencies in the use and organization of a makerspace. In this module, we work with IT design, laser cutters, vacuum former, 3D printers etc.

STEP 1

The students answer the following questions:

- What affects how fast the rotor turns?
- Which aspects of the blade can you adjust?
- How can you test it?

STEP 2

The students watch an introductory video on the aerodynamics of a wind turbine.

The Physics of Windmill Design (youtube.com)

STEP 3

Paper Airplane

The teacher introduces aerodynamics with a focus on the forces affecting propulsion, lift, drag, and gravity. The students make and test paper airplanes, illustrating the importance of the four forces. See the Support Material for a detailed step-by-step instruction.

STEP 4

Aerodynamics

The teacher gives an overview of which wind forces to account for when designing rotor blades. The teacher and students discuss the relationship between head wind and rotational wind (air resistance) and calculate the total collected wind force using the Pythagorean theorem. See the Support Material for more details.

STEP 5

Introductory experiments

The students conduct a range of experiments on rotor blades with fixed designs with different lengths, widths, angles and bends, to prepare them for designing and improving their own rotor blades in step 6. All groups fill in their own table such as the one shown on the right. See the Support Material for more details.

Before the experiment, the students discuss and make hypotheses in groups about which rotor blades they expect will generate the most electricity.

	Efficiency (Joule generated over 60 sec.)		
	Rep. 1	Rep. 2	Rep. 3
Angled: (0°)			
Angled: (10°)			
Angled: (30°)			
Width: (30mm)			
Width: (50mm)			
Length: (140mm)			
Length: (170mm)			
Number of blades: (3)			
Number of blades: (6)			
Bend: (Bended)			
Bend: (Not Bended)			

STEP 6

Design, build, test, and improve your own wind turbine blades

The students start designing and testing various shapes and sizes of rotor blades. Afterwards, the best performing wings are bended to improve the design further. The number of blades should be fixed for better comparison between the groups. See the Support Material for a step-by-step guide.

Another option is to build the windmills/ turbines using household objects, e.g., plastic bottles, cardboard, stick, a fan etc. For further description and procedural details see the Support Material.

Alternatives to the LEGO components are available, e.g., a bike generator connected to an ammeter.

Figure 11: Different designs of laser cut rotor blades

MAKERSPACE

Materials:

- Laser cutter, vacuum former, wind machine, LEGO-set-9686, and LEGO-set-9688, heat gun, acrylic bending machine, heat resistant gloves, ready-to-use LEGO wind turbine towers

Procedure (construction):

- Design and cut the rotor blades on the laser cutter.
- Bend the rotor blades using heat guns or acrylic bending machine

Procedure (test):

- Gather the students and discuss how to test the efficiency and the scientific practice (where to place the test, the windmills/turbines, the wind machine, length of tests, etc.)
- Test the efficiency of the wind turbines using the wind machine and LEGO energy-meter.
- Collect all data and results for the following presentation


*unge forskere
Skalaforståelse
KOMMUNIKATION
Factfulness-regler
Imagine bending lines
4 Calculate the risk
5 Check the proportions
6 Question your categories
Notice slow changes
8 Use multiple tools
FOR-TÆLLING
Engagere
Foran-dring
Forklare
Oplyse
DATA

STEP 7

Make a poster

Each student group creates a poster from which they will present their wind turbines (see fig. 12 for inspiration). The posters contain drawings/pictures of their wind turbine, of all their prototype blades and their test results. The posters also show the students' considerations on material choice and ideas for further improvements of the blades if given more time.

STEP 8

Present your wind turbine, rotor blade design, results, improvements and materials of choice

The student groups present their projects for the rest of the class.

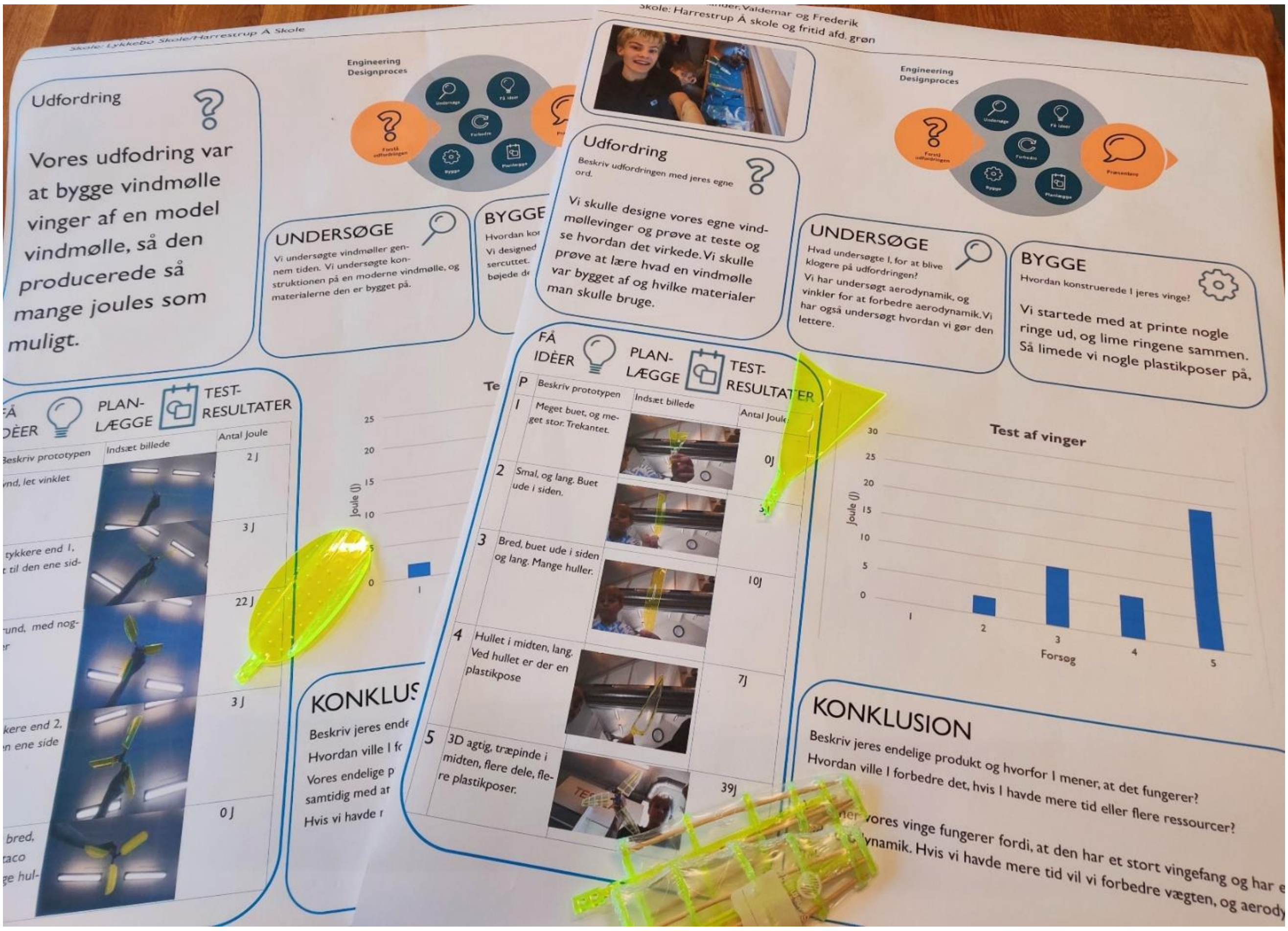


Figure 12: Examples of student posters showing the different tests and test results

SUPPORT MATERIAL FOR THE TEACHER

As a help to teachers implementing this toolkit, we have developed a Support Material. The Support Material gives the teachers further information and instruction on carrying out each module.

The Support Material contains the following areas of information:

Theoretical aspects

- History of windmills
- Materials for rotor blades and wind turbine towers
- Environmental impacts of wind turbine production
- Aerodynamics

Classroom discussions

- Renewable versus non-renewable sources of energy; their advantages and disadvantages
- Materials of wind turbine production

YouTube videos

- The physics of wind turbine design

Step-by-step guides and instructions

- Build your own windmill type
- Recycling and testing materials
- Paper airplane
- Introductory experiments: wind turbine blades
- Design, build, test, and improve your own wind turbine blades

To find out more you can use the following free resources from WindEurope Learn Wind:

- **Teachers Toolkit: Learning Wind Energy for Primary Schools**, toolkit, teaching material, primary-level education
- **Let the wind blow** book & video Explains climate change & wind energy
- **When I Grow up** book Inspires young adults to consider a career in clean energy
- **Wind Energy Basics** animation teaches users about wind energy technology
- **Offshore Wind 4 Kids** workshops demonstrate how offshore wind turbines work

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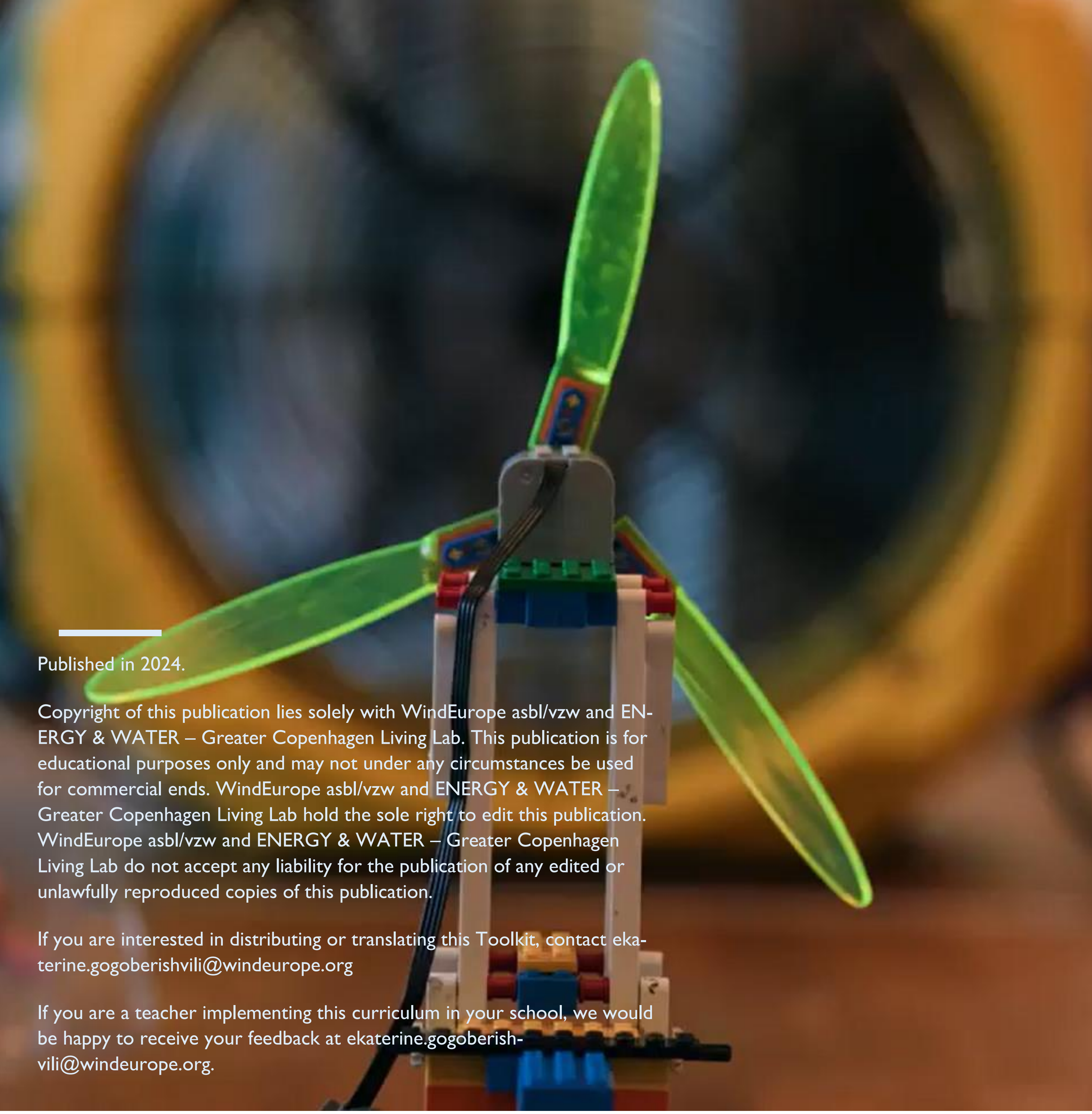

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If you are interested in distributing or translating this Toolkit, contact ekaterine.gogoberishvili@windeurope.org

If you are a teacher implementing this curriculum in your school, we would be happy to receive your feedback at ekaterine.gogoberishvili@windeurope.org.

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