Experiences with sustainable engineering and student-centered learning for 1 000+ students

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The courses

TEP4295 Sustainable engineering 7.5 ECTS *Concepts, assessment methods and strategies for sustainability.*	• Undergraduate, 200-250 students, multicampus Transformed from a teacher-oriented format last lectured in spring 2020, to a fully online version in 2021, and in 2022 offered as a hybrid (streamed) course in 2023.
INGX2300 Engineering systems thinking 10 ECTS *Innovation, entrepreneurship, technology management, and sustainable engineering.*	• **Undergraduate, approx. 1 000 students** • Multicampus, all NTNU's bachelor engineering programs in Trondheim, Gjøvik, and Ålesund Digital, shared course across all bachelor engineer programs 2022 and 2023.

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Student-centered

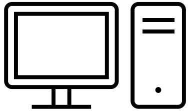
“students (…) lead learning activities, participate more actively in discussions, design their own learning projects, explore topics that interest them “ (*)

Teacher-centered

“ teacher tends to be the most active person (…) while students spend most of their time sitting in desks, listening, taking notes, giving brief answers to questions that the teacher asks, or completing assignments and tests” (*)

Large student numbers require use of the digital environment in **learning activities for sustainable engineering**

Digital environment



The digital learning environment is *“the totality of systems or applications that support teaching and learning.”* (**).

Scalable and resource efficient, yet also a **challenge for student-centered learning**.

(*) https://www.edglossary.org/student-centered-learning/
(**) https://www.surf.nl/en/controlling-the-digital-learning-environment

Sustainable engineering

1. Concepts, definitions, terms, goals, strategies, indicators and their status.

2. Methods and approaches for evaluating sustainability (industrial ecology methods)

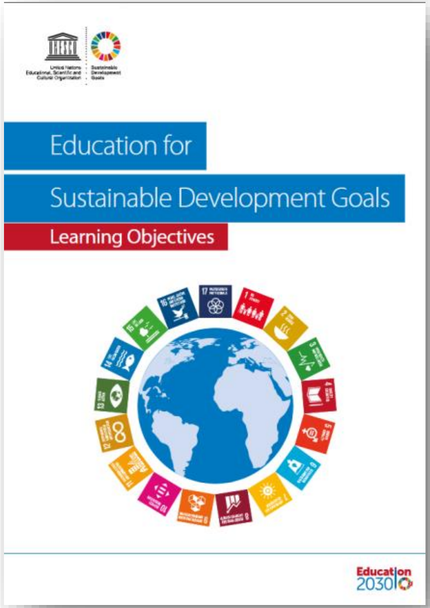
3. Professional development for a sustainable future

Knowledge.
What we mean with
engineering for sustainability

Skills.
How to evaluate and guide engineering and technology development

Competences.
key competences for sustainability and sustainable engineers

UNESCO Key competences for sustainability



Systems thinking competency
the abilities to recognize and understand relationships; to analyse complex systems; to think of how systems are embedded within different domains and different scales; and to deal with uncertainty.

Anticipatory competency
the abilities to understand and evaluate multiple futures – possible, probable and desirable; to create one's own visions for the future; to apply the precautionary principle; to assess the consequences of actions; and to deal with risks and changes.

Normative competency
the abilities to understand and reflect on the norms and values that underlie one's actions; and to negotiate sustainability values, principles, goals, and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge and contradictions.

Strategic competency
the abilities to collectively develop and implement innovative actions that further sustainability at the local level and further afield.

Collaboration competency
the abilities to learn from others; to understand and respect the needs, perspectives and actions of others (empathy); to understand, relate to and be sensitive to others (empathic leadership); to deal with conflicts in a group; and to facilitate collaborative and participatory problem solving.

Critical thinking competency
the ability to question norms, practices and opinions; to reflect on own one's values, perceptions and actions; and to take a position in the sustainability discourse.

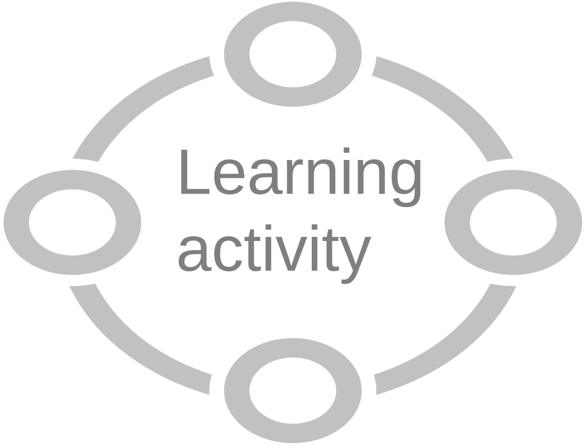
Self-awareness competency
the ability to reflect on one's own role in the local community and (global) society; to continually evaluate and further motivate one's actions; and to deal with one's feelings and desires.

Integrated problem-solving competency
the overarching ability to apply different problem-solving frameworks to complex sustainability problems and develop viable, inclusive and equitable solution options that promote sustainable development, integrating the above-mentioned competences.

Massive online course
MOOC-like digital course with reading and video material for self-paced individual and group study of sustainability concepts and strategies, with reflection questions, discussion boards, quizzes, etc.

Academic text with peer review
write a short academic paper "definitions of sustainability and relevance of sustainable engineering for your career", with anonymous peer-to-peer feedback and assessment.

Project-based learning
inter-disciplinary group work to develop and evaluate a new technological business concept within a given theme (e.g., "energy crisis").



Auto-graded computational assignments
self-grading assignments and training material (Jupyter Notebook, nb –grader): randomized exercises mimicking textbook examples and problems in LCA, MFA, IOA, energy analysis, economic assessment, footprinting.

Flipped classroom problems
in-class (or asynchronous) activity to discuss and reflect contents of the course, containing i) preparatory video and reading material, ii) problem description, and iii) digital tools, iv) digital channels for audio/video and written communication.

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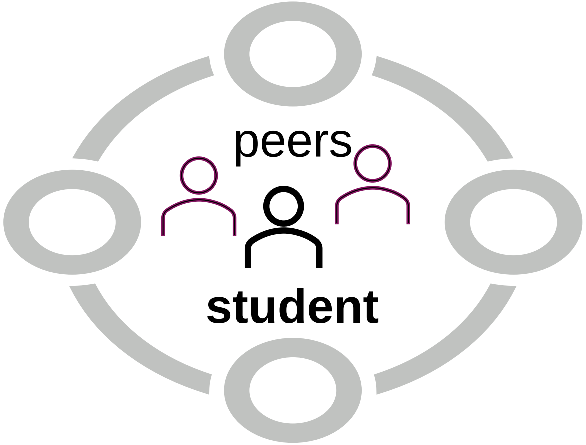

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Key competences for sustainability ⟺ Mapping ⟺ Learning activity

No.	Competency	Related abilities
1	Systems thinking competency	a. recognize and understand relationships; b. analyse complex systems; c. think of how systems are embedded within different domains and different scales; d. deal with uncertainty.
2	Anticipatory competency	a. unde b. creat c. apply d. asses e. deal v
3	Normative competency	a. unde b. negot confli
4	Strategic competency	a. collec susta
5	Collaboration competency	a. learn b. unde (emp c. unde d. deal v e. facilit
6	Critical thinking competency	a. quest b. reflec c. take a
7	Self-awareness competency	a. reflec b. conti c. deal v
8	Integrated problem-solving competency	a. apply probl promote sustainable development, integrating the abovementioned competences.

Learning activity
Project-based learning *inter-disciplinary group work to develop new business concepts within a given theme (Energy storage, Smart City, etc.)*
review *ns of sustainability and eering for their own career", eedback and assessment.*
onal assignments *raining material (Jupyter nized exercises mimicking ms.*
naterial *video material for self-paced ustainability concepts and ions, discussion boards,*
lems *vity to discuss and reflect ing i) preparatory video and scription, and iii) digital tools, iv) digital channels for audio/video and written communication.*

STUDENT-CENTERED LEARNING ACTIVITIES FOR KEY SUSTAINABILITY COMPETENCIES IN ONLINE COURSES WITH MANY STUDENTS

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CHALMERS UNIVERSITY OF TECHNOLOGY

19th International CDIO conference, Trondheim June 2023

19th International CDIO Conference 26–29 June 2023 NTNU, Trondheim, Norway

Project-based assignment

INGx2300: 10 weeks, through the course

5-6 person groups, across minimum 2 engineering programs

Develop a business and technology concept for an *Energy crisis in Europe*, to describe

- Concept and market opportunities
- Costs and revenues
- Environmental and sustainability aspects.

Consider trends and change towards 2030.

Deliverables

Physical, at home campus.

Week 1 Group formation, concept kick-off

Digital support.

Week 4	Group collaboration agreement
	Concept draft
Week 6	Mid-term peer-to-peer presentation
Week 7	Communication log
Week 10	Final report (summative grade)

Flipped classroom

Individual classroom sessions, each of 2h.

Learning management system elements:

- Reading and other preparatory material.
- On-boarding quiz.
- Uses 3rd party and/or inhouse digital tools and simulators.
- Digital communication channels used during sessions (Zoom, discussion boards).

Entirely online (INGGX2300), or hybrid stream (e.g., TEP4295 in 2023).

Session example: **climate policy**

1. Groups are assigned a **random country**: gather sustainability information about the country, such as human development index, gross domestic product, energy and health statistics.
2. **Negotiate within their group a global policy for achieving the Paris target** of 1.5 degrees considering these other 'national' sustainability interests and needs.
3. Test and validate the climate policy with a **global climate policy simulator** (En-ROADS).
4. **Present policies in open plenary and discuss** them from the perspective of the countries present.

- Involves a holistic perspective and system effects
- Understanding and negotiating views and values
- Critical reflection and integrated problem solving
- Collaborative and cooperative learning

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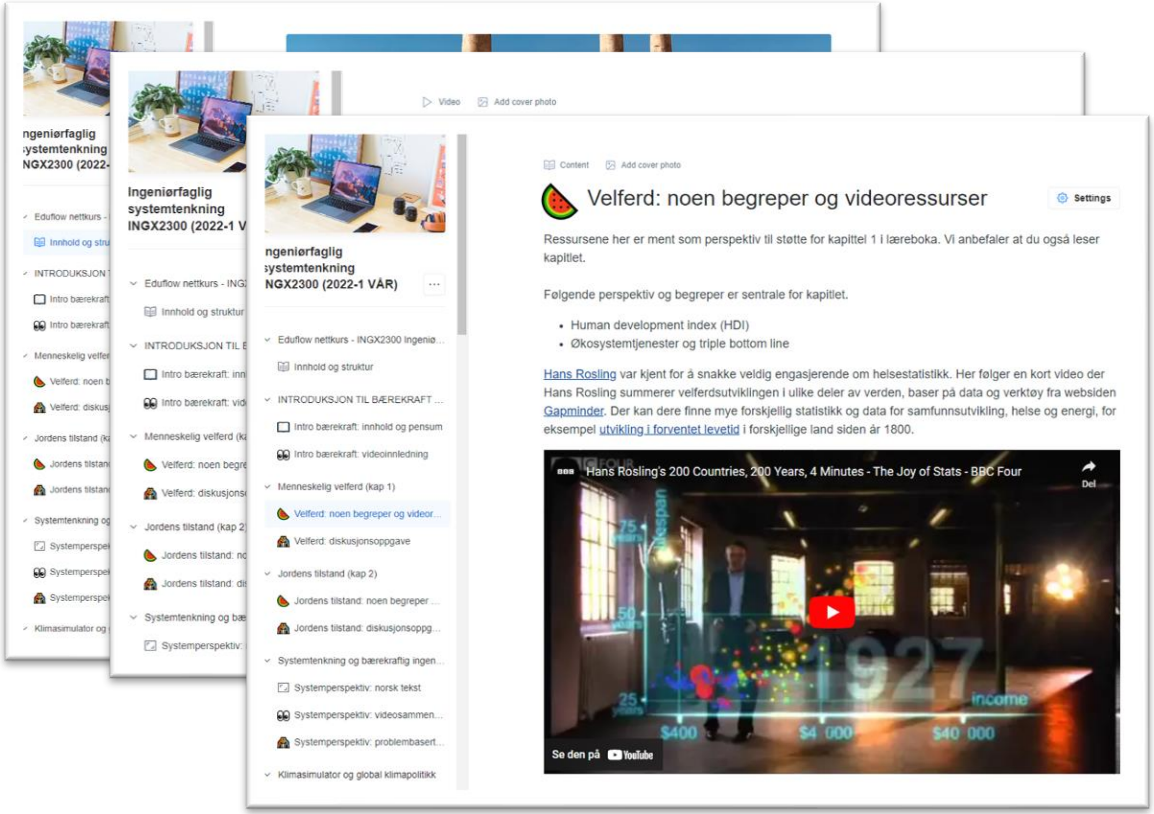
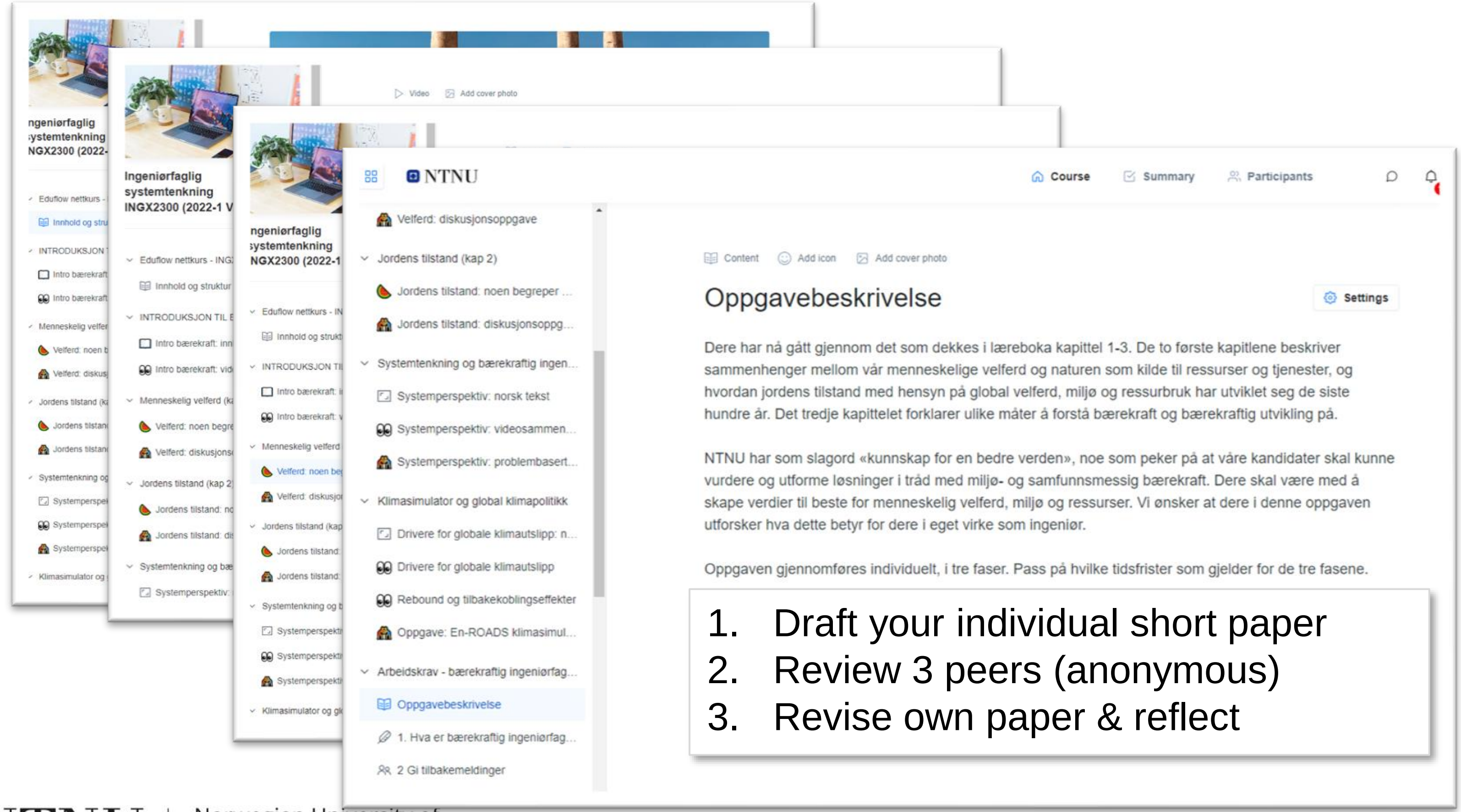
Sessions

- Global climate policy, how to achieve Paris agreement of 1.5 degrees
- Simplified LCA: plastic vs reusable grocery-bag
- Allocation in LCA: milk farm products
- Material flow analysis: clothes in Norway
- Carbon footprint: one student year
- Energy assessment: windfarm concept
- **Indigenous land rights: windmills**
- Industrial symbiosis in process industry cluster

Online self study (MOOC)



Peer-to-peer review



1. Draft your individual short paper
2. Review 3 peers (anonymous)
3. Revise own paper & reflect

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MOOC-like digital course with reading and video material for self-paced individual and group study of sustainability concepts and strategies, with reflection questions, discussion boards, quizzes, etc.

Project-based learning
inter-disciplinary group work to develop and evaluate a new technological business concept within a given theme (e.g., "energy crisis").

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Which one do you think is difficult to scale-up in a digital environment, and why?

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- Well received. Students speed through and revisit later.
- Replacement for the book?
- Few complete discussion problems, but also how many do the chapter questions for a book?
- Sometimes the pedagogics is lost (logo quiz example)

Academic text with peer review
write a short academic paper "definitions of sustainability and relevance of sustainable engineering for your career", with anonymous peer-to-peer feedback and assessment.

- Very good fedback on the task, and format
- «I have not written a text like this since high school»

- Highlights gaps in competence for programming
- Few make use of the training material
- Forces skills development but difficult to allow deep learning for sustainability

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inter-disciplinary group work to develop and evaluate a new technological business concept within a given theme (e.g., "energy crisis").

- Generally, the more appreciated activity
- Difficult to provide feedback to groups; how can we scale-up formative assessment?

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Experiences

Activity-competence mapping identifies these as *integrative* activities

- **Connect very many** of the key competences
- Important for collaboration and strategic competence, and **integrated problem solving.**

- Diminishing participation through the semester
- Few active groups, many join as individuals
- The digital environment poses a significant challenge to engage active participation

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Project-based learning

inter-disciplinary group work to de... evaluate a new technological busin... ...pt within a given theme (e.g., "energy crisis").

Are they effective for student-centered learning at scale?

- They do enable autonomous and active participation, as individuals and groups
- Active participation **promotes life-long learning competence** such as growth mindsets, self-efficacy, and self-regulation.
- Some only engage the motivated students

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Conclusions

- Sustainable engineering and student-centered learning can be supported in a digital environment.

  However, it depends on use of **integrative, less scalable activities.**

- Successful scaling requires on-boarding and students' **active ownership of learning**.

  Will also promote life-long learning ability: growth mindset, self-efficacy and self-regulation.

- **Resource effectivity of education** is a general challenge and not specific to sustainability education.

- Student-centered learning at scale is an under-researched topic, but likely requires **change in both teacher and learner practices**.

- Accessibility of **AI tools underlines the importance of developing students' self-motivation.** New tools remove or reduce the applicability of assignments as "external motivation" for learning and learning activities.

Thank you for your attention

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in | Google Scholar | ORCiD | ResearchGate

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