



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.



NTNU

Norwegian University of
Science and Technology

Pettersen. NORDTEK 2023 Aarhus

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Defining properties

- Many students
- Several campuses
- Digital learning environments
- Content that should involve curiosity, reflection, dialogue; *engineering within the frame of society.*

Student-centered



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

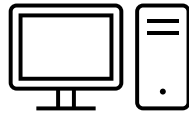
Teacher-centered



“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.

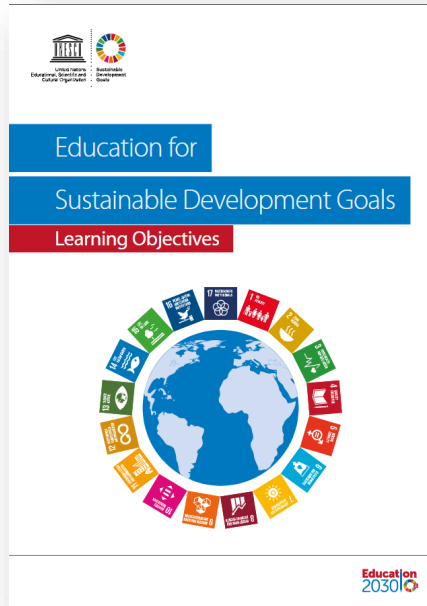
How to evaluate and guide engineering
and technology development

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

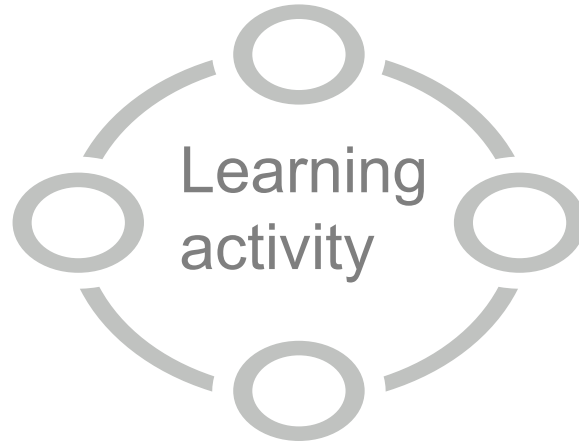
MOOC-like digital course with reading and video material for self-paced individual and group study of sustainability concepts and strategies, with reflection questions, discussion boards, quizzes, etc.

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”).



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.

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.

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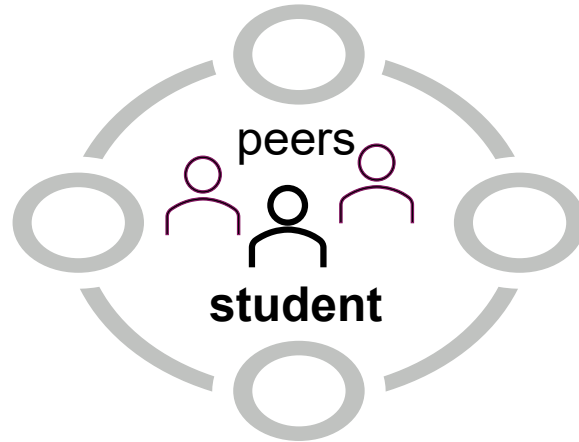
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Key competences for sustainability

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
3	Normative competency	a. unde b. negoti confli
4	Strategic competency	a. collec susta
5	Collaboration competency	a. learn b. unde (emp c. unde d. deal e. facilit
6	Critical thinking competency	a. quest b. reflec c. take
7	Self-awareness competency	a. reflec b. conti c. deal
8	Integrated problem-solving competency	a. apply probl promote sustainable development, integrating the abovementioned competences.

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

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19th International CDIO conference, Trondheim June 2023

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

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feedback and assessment.

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communication.

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



Flipped classroom

Individual classroom sessions, each of 2h.

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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)

The screenshot displays a MOOC interface for the course 'Ingeniørfaglig systemtenkning ING2300 (2022-1 VÅR)'. The left sidebar shows a navigation menu with various topics like 'Eduflow netturs -', 'INTRODUKSJON TIL', 'Menneskelig velferd', 'Jordens tilstand', 'Systemtenkning og bærekraft', and 'Klimasimulator og global klimapolitikk'. The main content area shows the course title and a list of topics. The right panel displays a video player for 'Velferd: noen begreper og videoressurser'. The video player includes a title bar with 'Content' and 'Add cover photo' buttons, a video player with a play button, and a description: 'Ressursene her er ment som perspektiv til støtte for kapittel 1 i læreboka. Vi anbefaler at du også leser kapitlet.' Below the description, there are two bullet points: 'Human development index (HDI)' and 'Økosystemtjenester og triple bottom line'. A link to 'Hans Rosling' is provided, followed by a paragraph: 'Hans Rosling var kjent for å snakke veldig engasjerende om helsestatistikk. Her følger en kort video der Hans Rosling summerer velferdsutviklingen i ulike deler av verden, baser på data og verktøy fra websiden [Gapminder](#). Der kan dere finne mye forskjellig statistikk og data for samfunnsutvikling, helse og energi, for eksempel [utvikling i forventet levetid](#) i forskjellige land siden år 1800.' Below the text is a video player showing a man standing in front of a large screen displaying a world map and data. The video player has a title bar with 'Hans Rosling's 200 Countries, 200 Years, 4 Minutes - The Joy of Stats - BBC Four' and a play button. The video player also has a 'Sø den på YouTube' button.

Peer-to-peer review

The screenshots illustrate the NTNU course environment for 'Ingeniørfaglig systemtenkning NGX2300 (2022-1)'. The interface includes a sidebar with navigation links, a main content area with a course structure, and a detailed assignment description page.

Course Structure (from middle screenshot):

- Intro bærekræft
- Intro bærekræft
- Menneskelig velferd
 - Velferd: noen begreper
 - Velferd: diskusjonsoppgave
- Jordens tilstand (kap 2)
 - Jordens tilstand: noen begreper
 - Jordens tilstand: diskusjonsoppgave
- Systemtenkning og bærekraftig ingeniørfag
 - Systemperspektiv: norsk tekst
 - Systemperspektiv: videosammenheng
 - Systemperspektiv: problembasert
- Klimasimulator og global klimapolitikk
 - Drive for globale klimautslipp: n...
 - Drive for globale klimautslipp
 - Rebound og tilbakekoblingseffekter
 - Oppgave: En-ROADS klimasimul...
- Arbeidskrav - bærekraftig ingeniørfag...

Assignment Description (from rightmost screenshot):

Oppgavebeskrivelse

Dere har nå gått gjennom det som dekkes i læreboka kapittel 1-3. De to første kapitlene beskriver sammenhenger mellom vår menneskelige velferd og naturen som kilde til ressurser og tjenester, og hvordan jordens tilstand med hensyn på global velferd, miljø og ressursbruk har utviklet seg de siste hundre år. Det tredje kapittelet forklarer ulike måter å forstå bærekraft og bærekraftig utvikling på.

NTNU har som slagord «kunnskap for en bedre verden», noe som peker på at våre kandidater skal kunne vurdere og utforme løsninger i tråd med miljø- og samfunnsmessig bærekraft. Dere skal være med å skape verdier til beste for menneskelig velferd, miljø og ressurser. Vi ønsker at dere i denne oppgaven utforsker hva dette betyr for dere i eget virke som ingeniør.

Oppgaven gjennomføres individuelt, i tre faser. Pass på hvilke tidsfrister som gjelder for de tre fasene.

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

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”).

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

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.

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Experiences

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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.

- 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 feedback 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

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.

- Generally, the more appreciated activity
- Difficult to provide feedback to groups; how can we **scale-up formative 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”).

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.

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**

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.

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Project-based learning

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Massive online course

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



Academic text with peer review

write a short academic paper on the definitions of sustainability and the relevance of sustainable engineering for your field, 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”).



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

Auto-graded computational assignments

self-grading assignments and training material (Jupyter Notebook, nb-grader): randomized problems mimicking textbook examples and problems in IOA, energy analysis, economic assessment, etc.



Flipped classroom problems

in-class (or asynchronous) discussion to discuss contents of lecture, containing i) preparatory video and reading material, ii) problem description, and iii) digital tools, iv) digital channels for audio/video and written communication.



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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Google Scholar

ORCID

ResearchGate



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