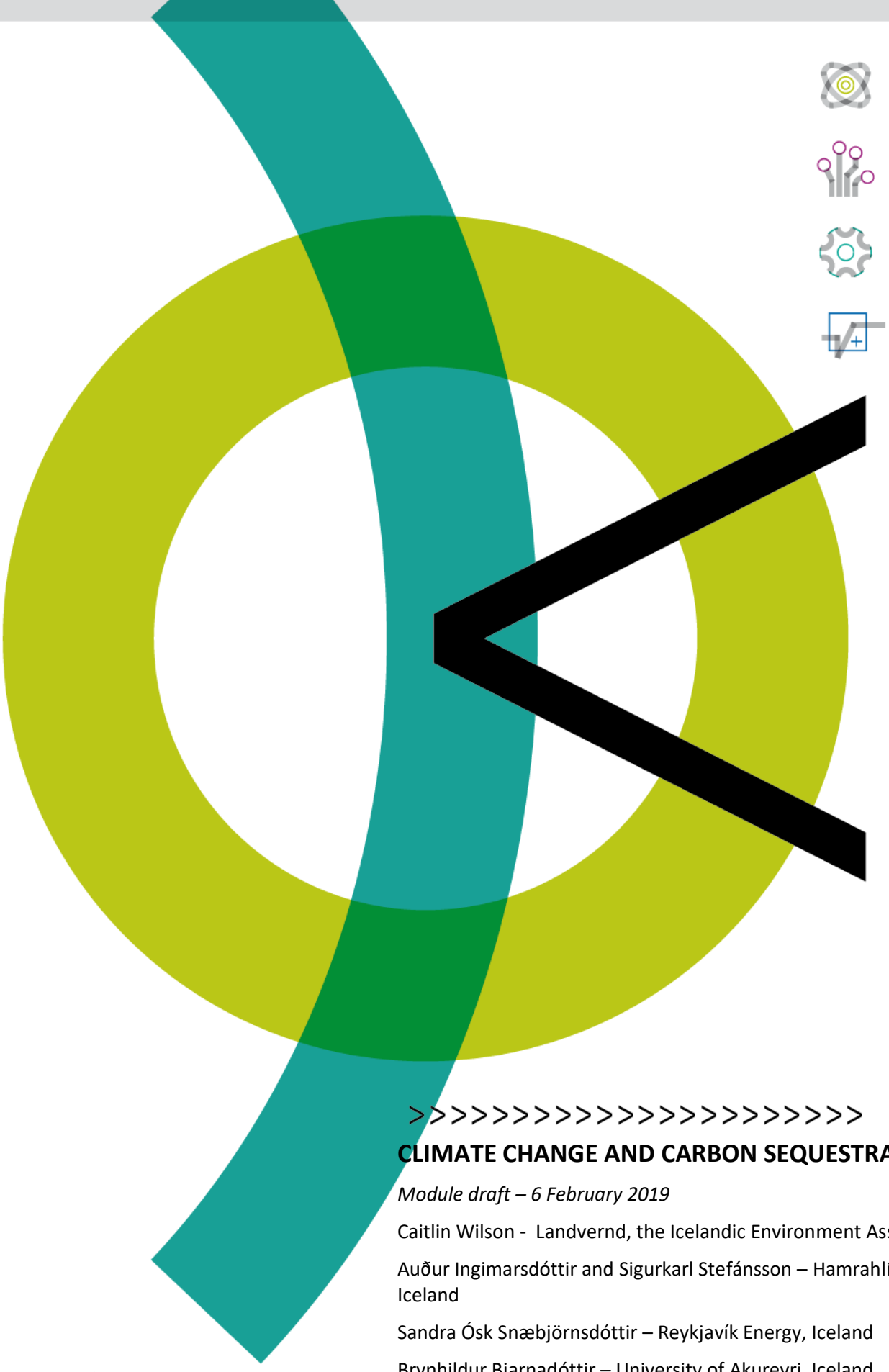

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CLIMATE CHANGE AND CARBON SEQUESTRATION

Module draft – 6 February 2019

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It's your time to imagine the futures

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Overview of the module

Climate change poses one of the greatest challenges to the future of the planet. In this module, students learn about possibilities for carbon sequestration as a means of combatting climate change. Students gain understanding of the scientific processes of carbon sequestration through reforestation and through mineralisation, including how to calculate amounts of carbon sequestered and compare to amounts of CO_2 emissions.

Because of the importance of climate change to the future, the module addresses and works with the future to build students' imagination of possibilities and alternative future scenarios. The module uses examples from cutting edge research and interviews with researchers to expose students to real, empowering future possibilities for themselves and the world. Agency and action competence activities task students with applying critical, creative thinking to design strategies for influencing systems and to imagine their role in a desirable future.

The duration of the full module is ca. 20 teaching hours, but the activities can be taken individually as well. The module is transdisciplinary and can be taught in geology, biology and chemistry and it relates to social sciences and arts.

The module was developed and piloted in Iceland from 2017 to 2019 at Hamrahlíð College in collaboration with Landvernd, the Icelandic Environment Association, and with expert contributions from Sandra Ósk Snæbjörnsdóttir of Reykjavík Energy and Brynhildur Bjarnadóttir of the University of Akureyri.

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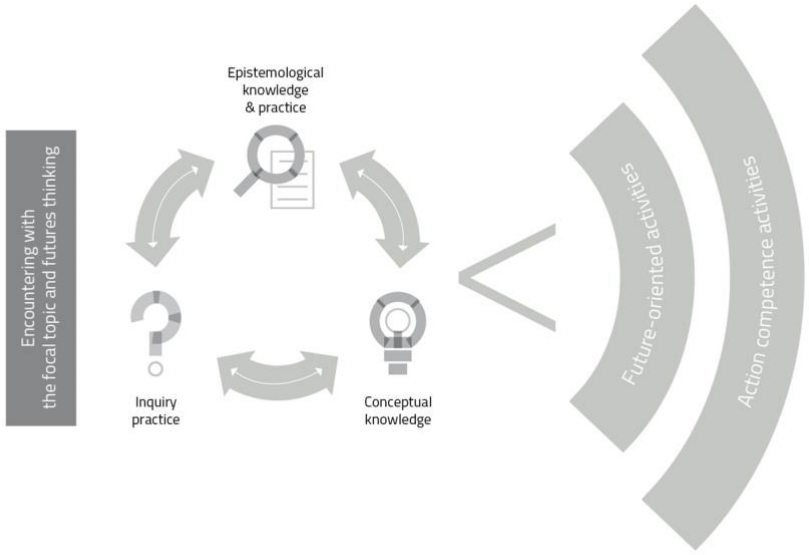
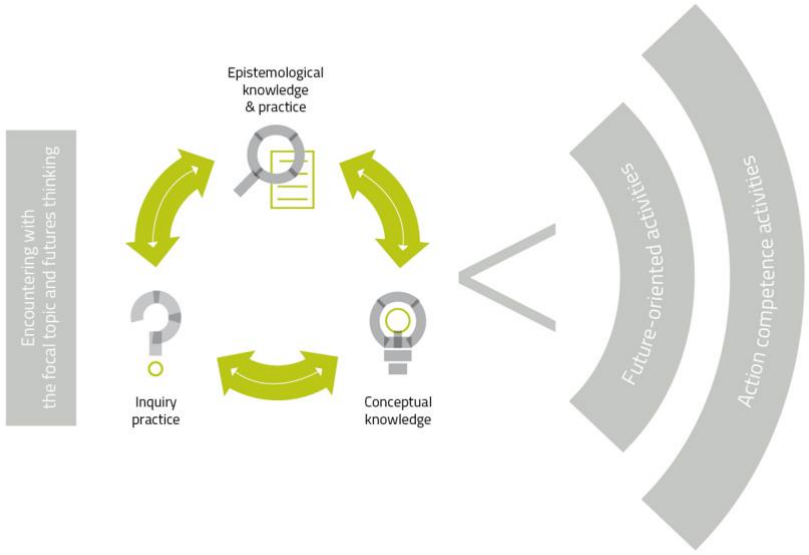
ACTIVITY 1: Introduction to climate change and carbon sequestration

Position in the module: ***Encountering with the focal issue***	 The activity consists of an overview lecture on the topics of climate change and carbon sequestration. The lecture aims to introduce the fundamental conceptual and epistemological knowledge required to understand and be able to work with calculating carbon sequestration and analysing the climate system, as these will be developed and deepened in the other activities in the module. Topics in the lecture include: • Chemistry of carbon dioxide • Human-induced change in CO_2 concentration • Positive and negative feedback and the greenhouse effect • Mitigation actions for climate stabilisation • Chemistry of combustion • Chemistry of photosynthesis • Organic and inorganic carbon cycle • Chemistry of carbon sequestration through mineralisation

Goals	***conceptual*** • To understand the basic chemical characteristics of carbon dioxide and its role in the greenhouse effect • To observe and interpret graphical representation of change in atmospheric concentration of CO_2 over time • To recognise the most influential factors affecting atmospheric concentration of CO_2 • To grasp the meaning of positive and negative feedback cycles and relate to examples based on the greenhouse effect • To become familiar with possible mitigation actions to reduce atmospheric concentration of CO_2 • To recognise the role of CO_2 in the chemical reactions for combustion and photosynthesis • To relate the inorganic and organic carbon cycles to climate change • To learn the chemical reactions for carbon sequestration through precipitation as carbonate minerals • To become familiar with the research project CarbFix on carbon sequestration through mineralisation of dissolved CO_2 in basalt rock ***epistemological*** • To relate the climate change challenge with real world responses, including the CarbFix research project • To appreciate the complexity of the climate system and the system dynamics including feedback loops • To begin to break down disciplinary boundaries by learning about the climate system from different disciplinary perspectives ***social/emotional*** • To acknowledge the complexity of climate change and begin to overcome it through building understanding of the climate system • To realise that researchers are actively addressing the climate change problem
Time required	1 teaching hour

Materials	Slides
Teaching methods	The teacher lectures, explaining each concept carefully and checking for understanding with the class, especially on concepts which may be new such as feedback and carbon sequestration through mineralisation.
Tips for teachers from previous classroom experiences	The teacher should find own pictures where indicated in the slides.
Additional resources	

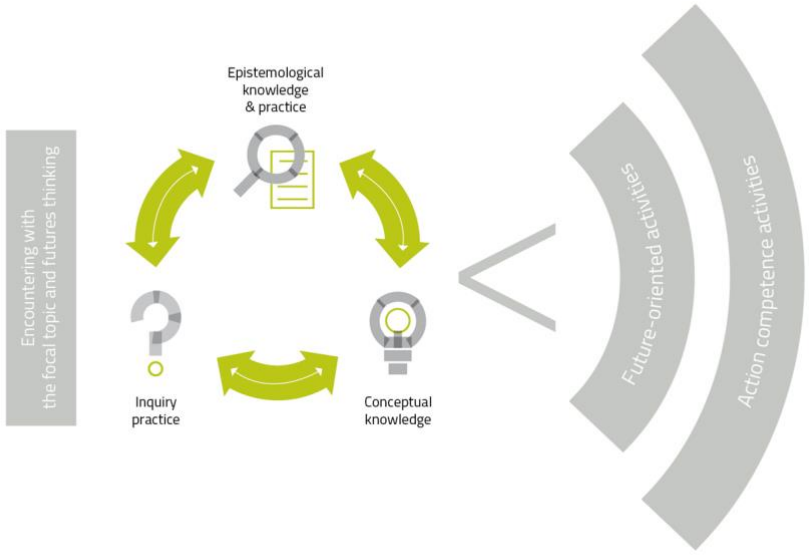
ACTIVITY 2: Measuring carbon sequestration through reforestation

Position in the module: ***Epistemological knowledge & practice*** ***Inquiry practice*** ***Conceptual knowledge***	 In this activity students get the opportunity to learn hands-on in the field how to measure and calculate the carbon content of trees. In the classroom, they relate these measurements and calculations to known amounts of carbon emissions. The main learning points of the activity include: • How to find out the height of a tree using the Pythagorean theorem • How to use tools to measure the diameter of a tree trunk • How to calculate the standing mass of carbon contained in a sample plot of forest from the biomass of the sample and extrapolate that to a larger area of forest • To relate the standing carbon mass to the amount of carbon binding per year for the forest • To compare amount of sequestration to emissions based on various CO_2-emitting activities
Goals	***conceptual***

	• To relate the greenhouse gas carbon dioxide to the chemical composition of trees • To understand how measuring biomass can be translated to give standing carbon mass • To relate the standing carbon mass and age of the forest to discover annual binding rate of the forest • To comprehend the scale of the calculations and be able to scale them up in order to compare to different kinds of emissions ***epistemological*** • To gain competence in using forestry tools including measuring tape, diameter fork, and height measure (pole or digital unit) • To be able to apply the Pythagorean theorem to find out the height of a tree • To appreciate differences of scale from sample plot of forest to larger areas of forest to different amounts of emissions by source ***social/emotional*** • To work together in a group to figure out how to use tools to take measurements • To work together in a group to figure out how to use information from measurements in calculations of standing carbon mass, annual binding, etc. • To appreciate the value of forests as carbon storage, but also as nature restorative places of well-being • To realise the scale of the potential of carbon sequestration through reforestation is comparable to current rates of greenhouse gas emissions
Time required	2-4 hours field work (visit to forest, measurements) 2 class hours calculating carbon sequestration through forestation
Materials	Calculation worksheet (word and PDF) Worksheet with solutions (word and PDF)

Teaching methods	The teacher takes the students to a forest and shows them how to measure the diameter and height of the trees, then lets them work independently (can be in groups) to take their own measurements. This can be an opportunity to plant tree seedlings if time and materials allow. Back in the classroom, the students use the worksheet to calculate the biomass of the sample plot of forest, and from that the standing carbon mass in the plot. They use this to calculate annual binding of the plot and extrapolate that to give the rate per hectare for the forest. Then, students can either calculate their carbon footprints or be given known amounts of greenhouse gas emissions in tonnes of CO_2 equivalent to compare to the figures found for the carbon sequestration of the forest. Finally, a discussion in which the teacher leads the students to understand the potential and value of reforestation as a tool to combat climate change.
Tips for teachers from previous classroom experiences	
Additional resources	Carbon footprint calculator

ACTIVITY 3: Measuring carbon sequestration through mineralization

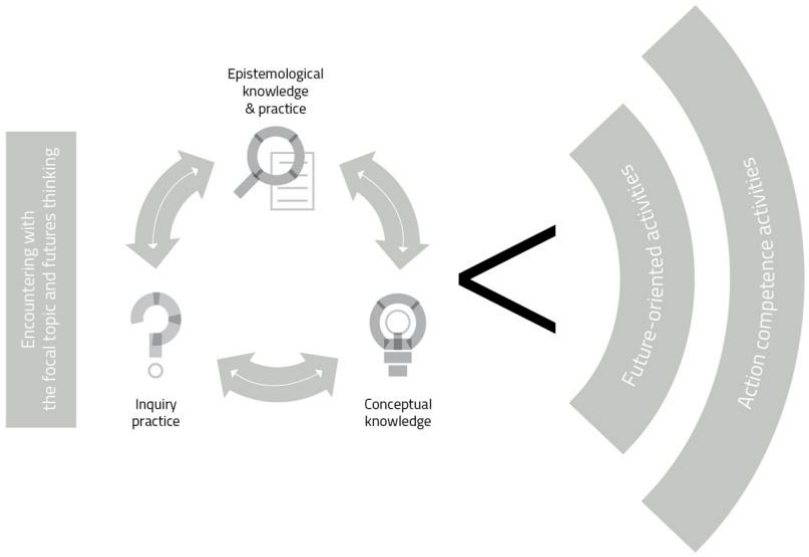
Position in the module: ***Epistemological knowledge & practice*** ***Inquiry practice*** ***Conceptual knowledge***	 In this activity students will gain competence in calculating theoretical quantities of carbon that can be sequestered through mineralisation, based on real-world, cutting-edge research. Students should have already encountered the focal issue of climate change and carbon sequestration before this activity, and after this activity they will be prepared for future-oriented activities and synthesis activities.

Goals	***conceptual*** • To understand concepts of carbon sequestration through mineralisation including precipitation of carbonate minerals and connective porosity • To relate these concepts to recent research using these chemical processes as a response to the need to reduce the amount of carbon dioxide in the atmosphere • To comprehend scales of chemical quantities ***epistemological*** • To explain how carbon sequestration through mineralisation works • To model the theoretical potential for carbon sequestration given density, size, chemical composition of minerals, and proportion of porosity • To relate sequestration calculations to real known amounts of carbon dioxide emissions • To understand how real world research works to develop the technology to mineralise carbon dioxide on the large scale ***social/emotional*** • To understand a real world solution to climate change • To imagine a possible future career as a scientist addressing climate change

Time required	2 class hours for completing the calculations 30 minutes for discussing the results of the calculations
Materials	Calculation worksheet (with answers) (word and PDF)
Teaching methods	*Guided calculations* Working in small groups, students are given the assumptions needed to calculate amount of carbon dioxide it is possible to sequester as different carbonate minerals. First, they calculate the amount of carbon dioxide contained in a piece of Iceland spar. Second, they calculate the amount of carbon dioxide sequestered in a core sample of porous basalt. Third, they calculate how much carbon dioxide it is possible to sequester in the ocean floor surrounding Iceland. Fourth, they calculate how much ocean floor (volume of porous basalt) is needed to sequester the annual emissions from Iceland and from the whole world. Finally, the teacher leads a discussion of the results of the calculations, posing questions to the students like:

	• What do these results mean for the possibility of sequestering carbon dioxide from the atmosphere through mineralization? • What do you think about this technological possibility? Did you know about it before? • What are some advantages and disadvantages to this technological process? • What are the ethics involved in this endeavor?
Tips for teachers from previous classroom experiences	Previous coursework in chemistry proved important for students to be able to understand and be able to complete the calculations. To help bridge this gap for students who did not have a chemistry background, the formulas were added into the worksheet.
Additional resources	See the worksheet (linked above) with solutions included for teachers.

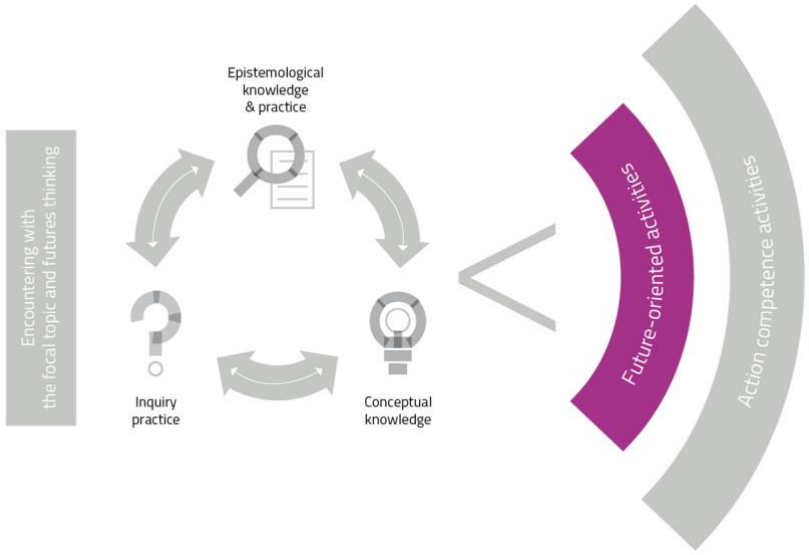
ACTIVITY 4: Exposure to carbon sequestration research

Position in the module: ***Bridging activity***	 The activity consists of two recorded interviews with scientists working on solutions to the climate change challenge. One scientist is working on the CarbFix research project on carbon sequestration through mineralization, see activity 3. The other scientist is working on carbon sequestration through reforestation, see activity 2. Both of these role models address how they became scientists and how they view the potential to influence the future for the better. The purpose of this activity is to let students relate personally to the research learned about in the previous activities by hearing directly from the people behind them. The scientists represent role models for the students and talk about the potential for STEM careers to change the climate system. This exposure activity serves to bridge between the two activities in epistemological and conceptual knowledge and inquiry practice to the future-oriented activities (numbers 5 and 6) by relating the scientific content to future possibilities.

Goals	***conceptual*** ● To reinforce knowledge of the core concepts of carbon sequestration learned in the first three activities ● To relate potential for carbon sequestration to climate change mitigation ***epistemological*** ● To recognize the significance of social, economic and political factors for scientific research ● To appreciate the diversity of pathways to STEM careers, and the diversity of STEM careers ***social/emotional*** ● To relate emotionally and personally to the life paths of two scientists working on solutions to climate change ● To open up students' minds to the possibilities STEM career offer for meaningful, influential work
Time required	1 hour total breaking down into: 15 minutes per interview 15 minutes discussion per interview
Materials	Interview recordings

Teaching methods	The teacher familiarizes her or himself with the research projects ahead of time, then introduces them to the students. The students watch the interviews, then in small groups look up further information about the researchers and their projects on the internet. They share their findings with each other. The teacher leads a discussion with the class about the researchers and their research projects, asking students what they think of them. The teacher can also ask students to imagine what kind of research they would be interested in doing themselves. This could be developed into a journal entry if the students keep future dream journals as part of the module.
Tips for teachers from previous classroom experiences	
Additional resources	Links to more research articles and videos from these research projects in carbon sequestration: • https://lup.lub.lu.se/search/publication/1397981 • http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.461.5367&rep=rep1&type=pdf • http://science.sciencemag.org/content/344/6182/373.full full article here • Energy Procedia article • Soil carbon sequestration for climate

ACTIVITY 5: My grandparents – Me – My grandchildren

Position in the module: ***Future-oriented activities***	 In this activity, students come to grasp the features of environment and society that make up their world, and compare these features in the past, present and in a desirable future of their imagination. Students are given interview questions to ask their grandparents or another elderly person. They then answer the same questions about themselves. Finally, they imagine what the answers could be for their theoretical grandchild in a desirable future. Discussion leads students through meaning-making around the kinds of changes that are possible over a few generations.

Goals	***conceptual*** • To understand key concepts in futures studies including possible, probable and desirable scenarios, forecasting and backcasting • To understand the environmental and societal factors that influence lived reality • To analyze societal and ecological aspects the past, present and future and compare them ***epistemological*** • To gain some competence in futures studies practices of foresight and anticipation • To apply a systems thinking perspective to deconstruct society into its component features ***social/emotional*** • To realize many alternative future scenarios are possible • To reflect on own feelings about futures • To engage in critical thinking and discussion with peers • To listen to, value, respect and gain insights from an elderly person • To fathom the significance of the crossroads between the human time scale and the geological time scale that students are living through • To open their eyes to the speed and degree of societal change that is possible in one generation
Time required	1 homework hour for the interview with a grandparent 1 class hour for sharing interview findings

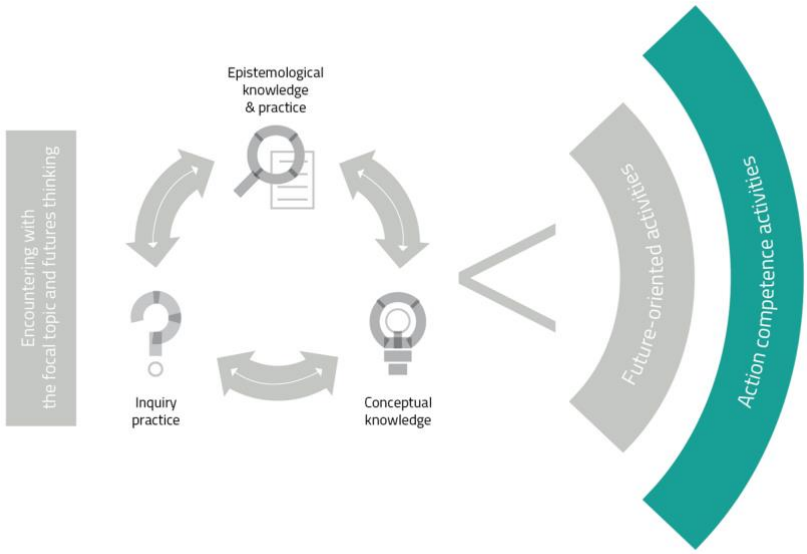
	1 class hour for answering the interview questions about themselves and about a hypothetical grandchild in a desirable future 1 class hour for sharing their desirable future visions and grandchildren's lives and for discussion
Materials	Slides "Future or Futures?" (ppt and PDF) Interview questionnaire (word and PDF)
Teaching methods	**Spark: „Future or Futures?"** a. Show a clip from The Man in the High Castle (e.g. here, first 60 seconds) and Inglourious Basterds (e.g. here). Afterwards, the teacher asks open questions such as: These events did not happen, but why did they not happen? Could they have happened? How do you feel watching these clips showing these events? b. The teacher leads brainstorming and discussion about the concept future. Students work in small groups to answer the questions. Create rough definitions for the words „future" and „futures" and explain why there is a difference between the two words. Discuss in your groups the following questions: • What determines what happens, how reality is? • What determines how the future will be? • Is only one future possible? The groups share with the rest of the class the main points of their discussions. c. The teacher ties the discussions together, making note of the main points common to all groups on the white board so that a „working definition" starts to appear for the words „future" and „futures". The teacher concludes this part by asking questions like: Have you thought about this before, how the future will be and why? Have you wondered about your own futures? How do you feel when you think about the future?

	Brief introduction to futures studies: „Possible, probable and desirable futures" a. Slides that build on resources from Peter Bishop that give an overview of the history and development of futures studies and ways to anticipate and interpret the future. **Activity: „My grandparents – Me – My grandchildren"** a. The teacher introduces the activity in which we will consider our grandchildren's futures in light of our grandparents' pasts, our current lives, in the context of sustainability and climate change. The teacher tells of their own grandparents and possible grandchildren, calculating the time period that could span from the birth of the grandparent to the end of the grandchild's life. The teacher paints a picture of the kind of changes that have taken place in the world since the birth of the grandparent and projects changes that could happen by the end of the grandchild's life. The main point: Incredible changes can take place in the world over short times. Refer to the point made by Andri Snær Magnason that aspects of the Earth that developed on a geological time scale are changing now on a human time scale. b. The teacher goes over the aspects of humanity and the world that we will compare from the past, present and futures. The aspects: housing, energy sources, water, air, lifestyles, culture, structure of society, economy, health, technology, ocean acidification and climate change. See the interview questionnaire. c. The teacher explains the steps in the activity. 1. Interview with a grandparent – see questionnaire. Completed outside of school time. 2. Analysis of the present. Completed in class in groups; students answer the same questionnaire themselves about the present. 3. In small groups, the students create a dream scenario for a desirable future.

	After the students complete the interview with their grandparents, they share out loud with the class how their grandparents answered the questionnaire. The teacher can be reflexive and highlight interesting and relevant points, e.g. about how much has changed over only two generations and therefore how much can change over only the next two generations, how some things were more sustainable, raise questions of well-being and quality of life and our perceptions of these. After sharing the findings out loud, discuss the following questions in small groups or with the class as a whole: • How many years are there between the birth of your grandparents and the birth of your grandchildren? • What has changed the most in this time? • What has caused these changes? • Is there something we can learn from the daily life in the time of our grandparents? Is there something we would rather not take with us? • If you could change something for your grandchild for the better, what would it be? Then the students answer the interview questions about their lives, again the teacher can be reflexive and facilitate some discussion of relevant points that come up. Then, in small groups, the students imagine a hypothetical grandchild and a dream future scenario for that child. They fill out the questionnaire for that child's dream future. This scenario can be a final product in itself, and the activity can end with the students sharing the lives of their future grandchildren. It can also work as the starting point for the action competence activity (activity number 6 titled "Realising possibilities for change").
Tips for teachers from previous classroom experiences	This activity is very flexible and teachers should make it their own. It worked well to stimulate students' creativity and imagination for the future, especially in light of their grandparents' answers to the questionnaire. That part made it a very personal activity, which worked very well to engage the students emotionally.

Additional resources	

ACTIVITY 6: Realising possibilities for change

Position in the module: ***Action competence activities***	 In this final activity, students get the opportunity to demonstrate the mastery they have built up during the module. In the first part of the module, they strengthened their grasp on fundamental epistemological concepts related to climate change and carbon sequestration. In the second part of the module, they measured and calculated the potential for carbon sequestration through vegetation and mineralization. In activity 5 in the module, they gained appreciation for the kinds of change that can happen over a few generations, and projected changes into the future. The purpose of this activity is to synthesize these new understandings and competences and relate them to students' personal and professional visions of the future and their role and purpose in the future.
Goals	**conceptual**

	• To demonstrate understanding of concepts fundamental to climate change by explaining a climate change problem of students' choice • To apply understanding of complex systems to analyze a problem's system • To apply understanding of system dynamics to find leverage points **epistemological** • To design a strategy to respond to a problem by influencing its system • To create a desirable future scenario for a problem • To use backcasting to describe and realise a desirable future scenario **social/emotional** • To use creativity in imagining desirable future scenarios, on personal, professional and societal levels • To role play and put yourself in the mindset of alternative future scenarios • To articulate a narrative in an engaging, stimulating way that opens up and makes real your future scenario for others
Time required	At least 2 class hours to complete the analysis 2-3 homework hours for groups to create their presentations 2 class hours for the groups to present their future stories
Materials	Slides (ppt and PDF)
Teaching methods	1. Future (re)visioning If you have done activity 5, revisit your vision for a desirable future. What do you think when you read it now? Have any of your ideas started to change? Now, revise or create a new vision for the future. How do you see yourself in, say, 15 years? What kind of a world do you live in? How do you live? What do you do?

	Put these future visions aside for later. 2. Problem analysis Find one problem related to climate change that you find interesting. Think back over the topics you have learned about in the module as well as topics you have learned about before or perhaps only heard about. Remember there are many aspects to climate change, not only meteorological but also ecological, social, cultural, economic, political and others. Choose a problem that calls to you, something you want to dig more deeply into. Find others who share this interest—we will need to form 4 groups of 6. Define the problem. See slides for directions and examples of defining, mapping and analyzing the problem and planning a solution. Write out a definition for the problem you have chosen. What exactly does it mean? Why is it a problem? What are the causes and consequences it implies? Mapping the problem. From your written definition, map out the elements of the system in which the problem exists. 3. Discovering "leverage points": opportunities for changing the system Looking over your map, evaluate how easily the aspects of the system you've identified can be changed. Use red to indicate aspects that are very difficult to change, yellow for aspects that would require something in order to change them, and green for aspects that can be changed easily or with the help of something that is easily acquired. Choosing your leverage point. Look again over your map, now focusing on the different leverage points you've identified and how difficult or easy they are to change, as you've evaluated. Think about the different kinds of change that can be used to influence a system, for example: technology, investment, infrastructure, policies, regulations, awareness, attitudes, values. Think also about feedback cycles and how their dynamics can be influenced. Choose one aspect you can and want to change in order to influence the system. 4. Imagining desirable futures

	Thinking about the futures that could be for the problem you've chosen. What are the probable, possible and desirable futures for this specific aspect you want to change? Think about how futures are different when they are based on reactions or actions (discuss difference between mitigation and adaptation—and perhaps beyond those two, creation?). Think about the different stakeholders and interests that can also influence the system. Imagine the multiple perspectives they represent, their motivations and their desires. Now, choose one future for your problem and the aspect you are working with, and describe it. It is the year 2034: What is the state of the problem? 5. Backcasting the solution Trace back, step by step, what happened during the past 15 years to achieve the change in the system you have described. Focus on the specific aspect you identified and the scenario for 2034 you envisioned. What is required to get to the 2034 you have chosen? What do you have to do? What is required of others? What material requirements do you need? What is your role in the change? Who do you want to be in this plan? What does your plan mean for your future personally and professionally? What obstacles did you encounter and how did you overcome them? What do you need to make this future come true? Keep in the back of your mind the different stories you heard from the researchers, how they represent different approaches to influencing different aspects of systems. Imagine how they became who they are and continue to change themselves. Think about how you are already becoming your future self, but how you also exist within a system. How can you influence the system you live in that determines what is probable, possible and desirable for you? 6. Articulating your strategy Based on the history you have written for the next 15 years, describe the strategy you will use to change the aspect of the system you can and want to change in order to address the problem you have chosen. 7. Creating your presentation Create a way to present your vision and plan to the group using any method of communication or media you like. Your presentation should last about 20 minutes (assuming they are in groups of 6, and total

	number of groups is 4). Think about how to make others understand your thinking process. Justify your choice of problem and aspect, and how you analyze the system you are working with. Tell how the world is in 2034, and specifically what the situation is for the problem you are addressing and the aspect you are using to influence the system of the problem. Tell about who you are and what your role is in the change. Explain what has happened over the last 15 years and how it happened. What strategy did you employ? What hindrances do you meet? What obstacles did you overcome? What failings did you experience? What were you able to accomplish and how? What did you use to be successful? Who helped?
Tips for teachers from previous classroom experiences	This activity involves many steps and each step needs time so students can sufficiently understand the point and fulfill the task. The teacher acts as a facilitator of this workshop-style activity, helping groups work through each step to build to their final product. Some students found it too complicated, and we tried a simplified version with fewer steps, but found that cut-down activity to be less meaningful than the full activity. Therefore it is important to give enough time. This activity makes a good final project for a course.
Additional resources	Futures scenarios workshop description VISIS method description