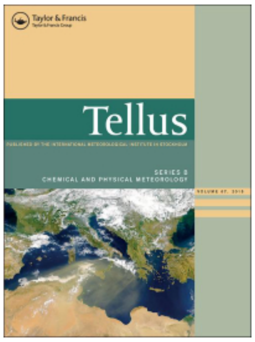
Society needs experts with climate change competencies : what is the role of higher education in atmospheric and Earth system sciences?

Riuttanen, Laura

2021-05-19

Riuttanen , L , Ruuskanen , T , Aijäla , M & Lauri , A 2021 , ' Society needs experts with climate change competencies : what is the role of higher education in atmospheric and Earth system sciences? ' , Tellus. Series B: Chemical and Physical Meteorology , vol. 73 , no. 1 , 1917862 , pp. 1-14 . https://doi.org/10.1080/16000889.2021.1917862

http://hdl.handle.net/10138/339716
https://doi.org/10.1080/16000889.2021.1917862



Tellus B: Chemical and Physical Meteorology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/zelb20

Society needs experts with climate change competencies – what is the role of higher education in atmospheric and Earth system sciences?

Laura Riuttanen, Taina Ruuskanen, Mikko Äijälä & Anniina Lauri

To cite this article: Laura Riuttanen, Taina Ruuskanen, Mikko Äijälä & Anniina Lauri (2021) Society needs experts with climate change competencies – what is the role of higher education in atmospheric and Earth system sciences?, Tellus B: Chemical and Physical Meteorology, 73:1, 1-14, DOI: 10.1080/16000889.2021.1917862

To link to this article: https://doi.org/10.1080/16000889.2021.1917862

Published online: 19 May 2021.

Tellus SERIES B CHEMICAL AND PHYSICAL METEOROLOGY
PUBLISHED BY THE INTERNATIONAL METEOROLOGICAL INSTITUTE IN STOCKHOLM

Society needs experts with climate change competencies – what is the role of higher education in atmospheric and Earth system sciences?

By LAURA RIUTTANEN*, TAINA RUUSKANEN, MIKKO ÄIJÄLÄ, and ANNIINA LAURI, *Institute for Atmospheric and Earth System Research, University of Helsinki, Helsinki, Finland*

(Manuscript Received 2 June 2020; in final form 13 April 2021)

ABSTRACT

The urgent societal need for climate action requires climate change expertise. But who is a climate change expert? What is the role of atmospheric and Earth system science education? In this study, we examine what competencies do atmospheric and Earth system scientists teach in selected programmes in seven European countries, and how they view the importance of various competencies for the students to learn. We also asked about teacher experiences and wishes related to teaching collaboration. We found that the atmospheric and Earth system scientists taught and valued the highest the traditional academic competencies related e.g. to critical thinking and applying knowledge. The normative, strategic and interpersonal competencies of sustainability were generally less valued and taught. The largest teaching gaps were found in competencies such as developing new ideas, interpersonal competency, making arguments and looking for solutions, critical thinking, collaboration and communication skills. Preferred collaborators for atmospheric and Earth system scientists were scientists from their own field or from other natural sciences, while collaborators from other sciences and wider society were less popular choices. The atmospheric and Earth systems scientists in our study did not see themselves as climate change experts. We foresee here a need to define climate change competencies.

Keywords: sustainability competencies, academic competencies, higher education, climate education

1. Introduction

The World, both in terms of the environment and societies, is changing at a rate not seen earlier in the history. Global Grand Challenges like climate change critically and urgently call for actions based on interdisciplinary research efforts. Education is a profound way of making a change in behaviour of individuals, leading to a societal change (Otto et al., 2020). But can the education answer the needs at the required pace?

In higher education, climate topics are often taught under the umbrella of atmospheric and Earth system sciences. However, it is not clear what climate change expertise mean and if necessary competencies are taught in the education of atmospheric and Earth system sciences. Here, we use atmospheric and Earth system science as a combination of atmospheric sciences, defined as study of structure and evolution of, and phenomena within planetary atmospheres (Wallace and Hobbs, 2006), and Earth system science, which focuses on interactions and feedbacks within the geospheres of the Earth (Jacobson et al., 2000).

As a reference, a competencies framework has been developed for the sustainability sciences by Wiek et al. (2011). Sustainability science is '… a field of research dealing with the interactions between natural and social systems, and with how those interactions affect the challenge of sustainability: meeting the needs of present and future generations while substantially reducing poverty and conserving the planet's life support systems' (Kates, 2011). As the fields are close to each other and partly overlapping, we use the framework developed for the sustainability sciences as a reference to approach the competencies taught in atmospheric and Earth system sciences. To our knowledge, no such a work has been done in the field of climate, atmospheric or Earth system sciences.

*Corresponding author. e-mail: laura.riuttanen@helsinki.fi

Citation: Tellus B: 2021, **73**, 1917862, https://doi.org/10.1080/16000889.2021.1917862

As climate change is a wide field, climate change expertise also is expected to cover a wide set of different competencies. It is improbable that a single field of science or an education programme could cover all of them. Due to the interconnectedness of the challenges, new collaborations between different fields of science as well as society are needed (Lehtonen et al., 2018). One option to bring in new competencies to an education programme is teaching collaboration. By teaching collaboration, we mean that a teacher teaches a course in collaboration with another teacher with the same or different field of expertise. The collaboration can happen within the same programme or unit, or across institutional boundaries. Good experiences have been found in teaching across institutes and fields of science (Lappalainen et al., 2014; Lauri et al., 2020) and in multidisciplinary intensive courses students learn many transferable skills that may be useful in their future working life (Ruuskanen et al., 2018). A teacher network can provide interdisciplinary learning on the complex social-environmental problem of climate change where students do not need to piece together different disciplines responses by themselves (Pharo et al., 2012). Perkins et al. (2018) conclude the importance of international approaches in climate change education to overcome the global challenge and that educators need more interdisciplinary and cross-cultural collaborations and more new and creative methods of teaching.

By this research, we aim at opening the discussion on whether the competencies currently taught in atmospheric and Earth system science higher education answer to the societal need of today in terms of the urgent need of climate change expertise. Our research aims at addressing the following questions: 1) Do atmospheric and Earth system scientists identify themselves as climate or climate change experts?, 2) Can competencies in atmospheric and Earth system higher education be described by the competencies of sustainability?, 3) How the studied atmospheric and Earth system scientists see the competencies they teach answer to the societal needs of today?, and 4) What kind of teaching collaboration do the studied atmospheric and Earth system scientists have or wish to have?

To answer these research questions, we examined selected study programmes in seven European countries. A survey was sent to two networks of atmospheric and Earth system scientists: participants of the EUROFLUX workshop in Finland in December 2018 and the Nordic Atmosphere-Biosphere Studies (ABS) network. These networks gather atmospheric and Earth System scientists from the Nordic countries and Europe. As the data in this survey was very limited, we completed the study by interviewing study programme representatives and analysing their programme's curricula. This research opening should be followed by more extensive, quantitative and statistical analyses of atmospheric and Earth system sciences and climate change competencies.

2. Theory and background

2.1. Competencies in higher education

Harmonizing of learning outcomes in formal education is formulated either as in European Qualifications Framework of skills, knowledge and their application (EC, 2015) or as Council for the Advancement of Standards in Higher Educations general higher education categories that include competences (CAS, 2015). However, Zlatkin-Troitschanskaia et al. (2016) state that harmonised learning outcomes in formal education are not enough and that generic higher education and field specific competences should be used. In addition to generic academic competences and their evaluation scales (DiPerna and Elliott, 1999), the emphasis in higher education has moved from the transmission of knowledge to the construction of new knowledge or more widely to research competences (Böttcher and Thiel, 2018). Common definitions of a competency involve, with minor variation the following elements: knowledge, skills (or abilities), attitudes, as well a context and a purpose where they are used (Wiek et al., 2011 and references therein).

2.2. Competencies in the study

In a literature review of the competencies of sustainability, Wiek et al. (2011) define sustainability competencies as 'A complex of knowledge, skills, and attitudes that enable successful task performance and problem solving with respect to real-world sustainability problems, challenges and opportunities', based on earlier work of Dale and Newman (2005); Rowe (2007) and Barth et al. (2007). Wiek et al. (2011) arrived at a synthesis result of five core *competencies for sustainability sciences (SC)*: (1) systems-thinking competency as the ability to collectively analyse complex systems across different domains (society, environment, economy, etc.) and across different scales (local to global), thereby considering cascading effects, inertia, feedback loops and other systemic features related to sustainability issues and sustainability problem-solving frameworks, (2) anticipatory competency as the ability to collectively analyse, evaluate, and craft rich 'pictures' of the future related to sustainability issues and sustainability problem-solving frameworks, (3) normative competency as the ability to collectively map, specify, apply, reconcile, and negotiate sustainability values, principles, goals, and targets, (4) strategic competency as the ability to collectively design and implement interventions,

Table 1. Sustainability competencies and their description used in the questionnaire, based on Wiek et al. (2011).

Competency	Competency concepts listed to respondents
Systems-thinking	Variables/indicators, sub-systems, structures, functions, Feedback loops, complex cause-effect chains, cascading effects, inertia, tipping points, legacy, resilience, adaptation, structuration, Across/multiple scales: local to global, Across/multiple/coupled domains: society, environment, economy, technology, People and social systems: values, preferences, needs, perceptions, (collective) actions, decisions, power, tactics, politics, institutions.
Anticipatory	Concepts of time including temporal phases (past, present, future), terms (short, long), states, continuity (dynamics, paths), non-linearity, Concept of uncertainty and epistemic status including possibility, probability, desirability of future developments (predictions, scenarios, visions), Concepts of inertia, path dependency, non-interventions, Concepts of consistency and plausibility of future developments, Concepts of risk, intergenerational equity, precaution.
Normative	(Un-)sustainability of current or future states, Sustainability principles, goals, targets, thresholds (tipping points), Concepts of justice, fairness, responsibility, safety, happiness, etc., Concept of risk, harm, damage, Concept of reinforcing gains ('win–win') and tradeoffs, Ethical concepts.
Strategic	Intentionality, transitions and transformation, Sustainability principles, goals, targets, thresholds (tipping points), Adaptation and mitigation, Success factors, viability, feasibility, effectiveness, efficiency, Obstacles (resistance, reluctance, path dependency, habits) and synergies, Instrumentalization and alliances, social learning and social movements.
Interpersonal	Functions, types, and dynamics of collaboration (within and beyond academia), Strengths, weaknesses, success, and failure in teams etc., thresholds (tipping points), Concepts of leadership, Limits of cooperation and empathy, Concepts of solidarity and ethnocentrism.

transitions, and transformative governance strategies towards sustainability, and (5) interpersonal competency as the ability to motivate, enable, and facilitate collaborative and participatory sustainability research and problem solving (Table 1).

Here, we study if these competences defined for sustainability science capture what is taught to future climate change experts in the field of atmospheric and Earth system sciences. As reference framework, we use *general academic competencies (AC)*, that are widely known and used in higher education and core skills in academic work (e.g. Havard, Hughes and Clarke, 1998; Van Dierendonck and van der Gaast, 2013; Mah and Ifenthaler, 2017). These have been recently examined e.g. by Tuononen et al. (2020) who listed 7 competencies: (1) applying knowledge, (2) collaboration and communication skills, (3) analysing and structuring information, (4) seeing different perspectives, (5) critical thinking, (6) making arguments and looking for solutions, and (7) developing new ideas.

2.3. Networks in this study

In the field of atmospheric and Earth system research, there is no joint network or forum where education would be discussed. Therefore, we used one of the active science networks, EUROFLUX, and one example of teacher networks, ABS, as basis of our study. Climate University is a rather new network in Finland, concentrating on climate change competencies, and their work has motivated our study.

- *EUROFLUX*

Euroflux was a European Commission funded project that started in 1996 to find out influence of terrestrial ecosystems and particularly of forests on biosphere-atmosphere interactions and their impact on the Climate System in Europe (Valentini, 2003). The project started with 14 partners, mainly university departments of forest science, ecology, agriculture or biology, one institute of hydrology and meteorology, two departments of physics that included meteorology and five research institutes. It ended in 1998 but the community has remained active and grown. The European Euroflux community has been central in establishing the European network ICOS, a research infrastructure with the aim of providing high quality European data on greenhouse gases and the carbon cycle, supporting climate action and decision-making (Franz et al., 2018). The 20th anniversary of EUROFLUX workshop was held in Hyytiälä, Finland, December 2018, participants were participants of the original organisations and the grown network. Education has not been in the focus of the EUROFLUX, but the workshop in December 2018 had also topics related to education.

- *The Nordic-Baltic Atmosphere-Biosphere Studies (ABS) network*

The Nordic-Baltic Atmosphere-Biosphere Studies (ABS) network started in 2006, when a joint Nordic master's programme carrying the same name was founded. The programme was financed mainly by national funds from Denmark, Finland and Sweden. However, for the joint activities such as student and teacher mobility and joint intensive courses, the funding granted by the Nordic Council of Ministers under the Nordplus programme was critically important. The ABS programme was a success, but in the constantly changing education environment it became increasingly challenging to run a joint programme that did not award joint or double degrees. Thus, ABS became gradually a network of local master's programmes. However, this never decreased the amount of collaboration. The network organises intensive courses, promotes student and teacher mobility, and develops new forms of activities such as joint online courses. Network meetings and workshops for teachers have been annual activities already for 15 years. The email list of the network reaches more than 50 active teachers and education managers in Denmark, Estonia, Finland, Greenland, Iceland, Norway and Sweden.

- *Climate University*

Climate University is a network of 11 universities in Finland to advance climate change and sustainability education in Finnish higher education, in collaboration with schools and the working life (blogs.helsinki.fi/climateuniversity). Climate University was established by the funding from the Finnish Ministry of Education and Culture, Finnish Innovation Fund Sitra and the participating universities in 2018. The network produces several joint open online courses on climate and sustainability topics by the end of 2020. A specialty in the Climate University network is that it combines all universities in Finland teaching atmospheric sciences to other universities teaching sustainability.

Prior to the production of the new joint online materials, Climate University mapped the education needs among all the partners and collaborators (Climate University Blog, accessed 30.5.2020; Äijälä and Riuttanen, 2019). The overarching question charted with the questionnaire was: 'What kind of expertise (education) is needed in the near future, in order to answer the challenges of climate change and sustainability?'. The answers highlighted the following themes: multi-disciplinarity, holistic understanding, impactful decisions (based on data and statistics), human perspective (choices, values, ethics, and principles), science communication (to inform political decision-making), including the private sector and markets, and the perspective of (educating) consumers and responsible citizens. It is to be noted that these themes largely resonate with the sustainability competencies arrived at by Wiek et al. (2011). This brief and limited study has provided us the motivation to study the relevance of these competencies in the field of atmospheric and Earth system science.

3. Methods

Two study surveys were sent out in Spring 2020: one teacher survey (Attachment 1) to the participants of the EUROFLUX conference in Hyytiälä, Finland, in December 2018 as well as the members of the ABS network, and another one to the teaching programme (Attachment 2) contacts of the institutions of the participants of the EUROFLUX conference and the ABS network. Also, websites of the respective 17 educational programmes were studied (Table 2). We selected degree programmes, which we considered to represent atmospheric and Earth system sciences, and which are operating in those higher education institutions (HEIs), which were represented in the EUROFLUX conference as well as the HEIs within the ABS network. Also, we restricted the study to programmes which had webpages in English, German, Finnish or Swedish.

In the *teacher survey*, we asked the teachers to evaluate how strongly the studied competencies are included in their teaching and in others' teaching in their institute, how important they see these competencies for the students to learn, and how familiar these concepts are to them. Sustainability competencies were defined in the questionnaires with the same key words as in Wiek et al. (2011) to explain their meanings (Table 1). We also asked about the teacher experiences and wished related to teaching collaboration. In the *programme survey*, we asked the programme representatives to evaluate, how strongly the studied competencies are included in the programme teaching, as well as the importance and familiarity of the concepts, and experiences and wishes on teaching collaboration. The respondents were asked to evaluate these in the scale ranging from 0 (not at all) to 9 (very much). We also asked for comments in open fields. More specifically, we asked about how they saw the competencies they teach (personally/in their institute/in their programme) answer to the societal needs of today.

We defined *a teaching gap* as a difference between the recognised importance of the competency and its weighting in teaching. *A knowledge gap* was defined as a difference between the importance and the familiarity of the competencies. These 'gaps' were used to identify if there is lack of teaching or lack of knowledge in the studied competencies. Two-tailed paired t-test was applied.

The survey data was supplemented by interviews conducted in February 2021. Interview requests were sent to the programmes presented in the programme survey. Interviews were conducted either via an online meeting tool or via email. The purpose of the interviews was to check if

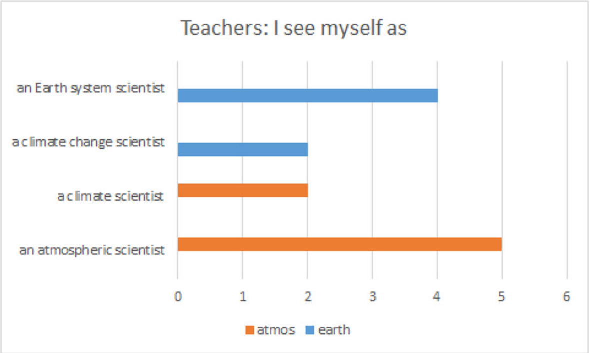


Fig. 1. How the respondents to the teacher survey see their field of expertise. Colours indicate if the respondents were classified as atmospheric (atmos) or Earth system scientists (earth). X-axis is the number of answers. The respondents were able to select multiple options.

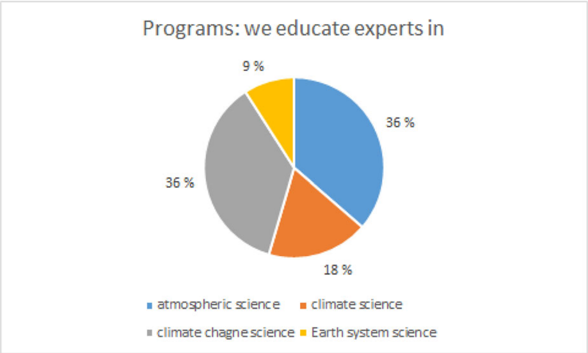


Fig. 2. How the respondents to the programme survey see the fields they educate experts in.

the programme representatives see the main findings and conclusions of our study represent their programme.

Prior to the interviews, we also studied the learning outcomes of the studied study programmes, as presented in the programme web pages (Table 2).

3.1. Description of survey data

We got nine answers to the teacher survey and six answers to the programme survey. Four out of six study programmes were interviewed. The following countries were represented: Belgium, Denmark, Finland, Germany, Iceland, Italy and Sweden. All the programmes answering the survey provided teaching in the master's level. Five out of nine teachers also taught mainly in the master's level; two out of nine in the bachelor level and two out of nine in the doctoral level. Main fields of science of the programmes were atmospheric science (2/6), geosciences (1/6), meteorology (1/6), physics (1/6) and one answered 'other'. The main fields of science for the teachers were biology or ecology (3/9), atmospheric science or meteorology (3/9), physics (1/9), chemistry (1/9) and one teacher answered 'other'. The programmes foresaw that they educate experts in atmospheric science (4/6), climate change science (4/6), climate science (2/6) and Earth system science (1/6). Five out of nine teachers considered themselves as atmospheric scientists, four out of nine as Earth system scientists, two out of nine as climate scientists as well as two out of nine as climate change scientists.

The responses from the programmes came from directors or study coordinators of the programmes. Six out of nine teachers were professors or associate professors, one was a university lecturer and two were researchers with teaching responsibilities. Eight out of nine teachers were male and one was female.

It should be noted that the number of responses was very limited, and while the data is quantitative, the sample is too small for statistical analyses. In our analysis we use a mixture of qualitative and quantitative methods, where the numeric results should be considered descriptive or indicative and their interpretation does not infer statistical significance. In Europe, there are in total 148 Master's Programmes giving education in atmospheric sciences and 104 in Earth system sciences (MastersPortal.com, accessed 6.10.2020). As the sending of the survey was based on the described networks, our sample selection was not random and does not necessarily represent the whole field.

4. Results

4.1. Identities of atmospheric and Earth system scientists

Based on the answers to the field of science and how the respondents foresaw the field of expertise they are educating in we found out two types of the respondents: *the atmospheric scientists* and *the Earth system scientists*. As atmospheric scientists we classified the respondents whose main field of science was atmospheric science, meteorology, physics or chemistry, and who foresaw that they educate experts in atmospheric science. As Earth system scientists we classified the respondents whose main field of science was biology, ecology or other, and who had answered that they educate experts in Earth system science. All of the teachers who foresaw themselves as climate scientists were atmospheric scientists while all of those identifying as climate change scientists were Earth system scientists (Fig. 1).

Five out of the six educational programmes were classified as atmospheric science programmes as they foresaw that they educate experts in atmospheric science and/or climate science and/or climate change science. None of the programmes were classified as Earth system science

Table 2. Universtity degree programmes that are part of the ABS network or had a member of faculty attending the Euroflux workshop were sent the programme questionnaire and their internet pages investigated (retrieved February 2020).

Degree programme	University	Level	Network
Master's Programme Atmospheric Sciences https://www.uibk.ac.at/studium/angebot/ma-atmosphaerenwissenschaften-15w/	University of Innsbruck	Master	Euroflux*
Master's Programme Environmental Meteorology https://www.uibk.ac.at/studium/angebot/ma-umweltmeteorologie/index.html.en	University of Innsbruck	Master	Euroflux*
Bachelorstudium Atmosphärenwissenschaften https://www.uibk.ac.at/studium/angebot/ba-atmosphaerenwissenschaften/infos-pruefungsreferate.html	University of Innsbruck	Bachelor	Euroflux*
Master's Programme in Geosciences https://www.uio.no/english/studies/programmes/geosciences-master/	University of Oslo	Master	ABS∘
Environmental Changes in Higher Latitudes https://enchil.net/	Agricultural University of Iceland	Master	ABS∘
Master's Programme in Environmental Science: Atmosphere-Biogeochemistry-Climate https://www.aces.su.se/education/masters-program/masters-programme-in-environmental-science-atmosphere-biogeochemistry-climate-change-es-abc/	Stockholm University	Master	ABS∘
Master's program in Atmospheric science, Oceanography and Climate https://www.misu.su.se/education/courses-and-programmes/master-s-programme	Stockholm University	Master	ABS∘
BSc in Physical Geography and Ecosystem Science https://www.lunduniversity.lu.se/sites/www.lunduniversity.lu.se/files/physical-geography-ecosystem-science-bsc-2020-fact-sheet.pdf	Lund University	Bachelor	ABS∘ & Eurolux*
Master's Programme in Atmospheric Sciences https://www.helsinki.fi/en/admissions/degree-programmes/atmospheric-sciences-masters-programme	University of Helsinki	Master	ABS∘ & Eurolux*
Sovellettu fysiikka, luonnontieteiden kandidaatti https://opintopolku.fi/app/#!/korkeakoulu/1.2.246.562.17.19767050529	University of Eastern Finland	Bachelor	ABS∘
Forest Ecology and Sustainable Management https://www.slu.se/en/education/programmes-courses/masters-programmes/forest-ecology-and-sustainable-management/	Swedish University of Agricultural Sciences	Master	Euroflux*
MSc in Environmental Engineering https://www.dtu.dk/english/education/msc/programmes/environmental_engineering#description	Technical University of Denmark	Master	ABS∘ & Eurolux*
Atmosphere, Climate and Ecosystems, Master's Programme https://utbildning.gu.se/education/courses-and-programmes/program_detail?programid=N2ACE	Gothenburg University	Master	ABS∘
Meteorologie M.Sc. https://www.sle.kit.edu/english/vorstudium/1986.php	Karlsruhe Institute of Technology	Master	Euroflux*
Master in Geography, Global change https://www.programmes.uliege.be/cocoon/20192020/en/formations/bref/S2UGGC01.html	University of Liège	Master	Euroflux*
Earth Sciences Master https://www.uni-heidelberg.de/en/study/all-subjects/earth-sciences/earth-sciences-master	University of Heidelberg	Master	Euroflux*
Earth Sciences Bachelor https://www.uni-heidelberg.de/en/study/all-subjects/earth-sciences/earth-sciences-bachelor-100	University of Heidelberg	Bachelor	Euroflux*

Contact persons were contacted for the degree programme's that are part of the Atmosphere-Biosphere Studies (ABS^) university network or if the University was the home organisation of the Euroflux* workshop participants.

programmes. The one programme classified as 'other' was about environmental engineering and did not answer to educate experts in any of the abovementioned fields (Fig. 2).

4.2. Results on competencies

We found out that the basic academic competencies (AC) were taught more, found out more important and they were more familiar to the respondents than the competencies of sustainability (SC) (Figs. 3–5). Especially the competencies of applying knowledge, critical thinking and analysing and structuring information were found out important and familiar, and they were present in the teaching. One individual respondent noted on academic competencies that 'all the points seem relevant', another one that 'It is very hard to estimate the relative importance of each competence, all are needed and they support each other'. Also, one respondent raises up that it is not clear '… how well we do that is not really known as it is quite difficult to evaluate'. One programme answer pointed that the academic competencies are generally relevant: 'All these competences are naturally very important and should be expected to have an important

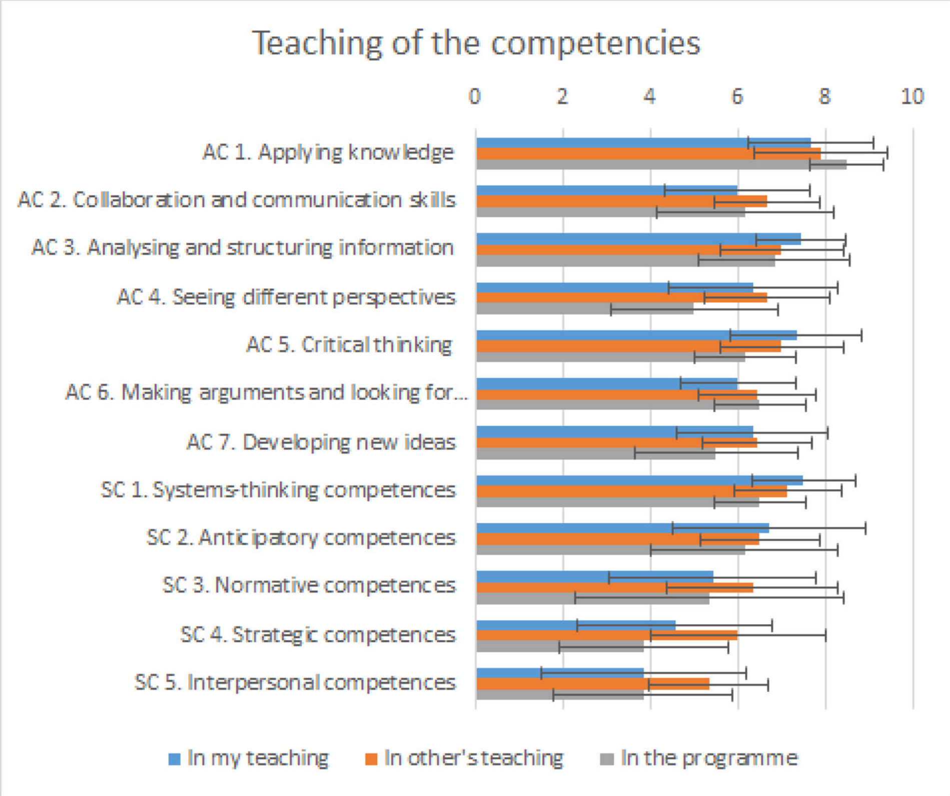


Fig. 3. Competencies in teaching. X-axis is how much on scale 0-9 did the respondents on average see they and their colleagues as well as the studied programmes teach the mentioned competencies. Values are averages of all answers and error bars show standard deviation (+/-1 STD).

place in all type of education.' All interviewees agreed that AC are taught more, found more important and are more familiar in atmospheric and Earth system higher education than SC. It was also found out that AC are more defined and described in the course syllabuses and learning outcomes.

Out of the sustainability competencies, the systems-thinking competencies were the most taught, familiar and found out as the most important. Systems thinking competencies were seen to be taught when teaching about climate system interactions, feedbacks and thresholds, or atmospheric and ecosystem processes. Words describing systems, processes and feedbacks were mentioned in the course syllabuses. The least known, taught and important were the strategic and interpersonal competencies. We also found out that these competencies were absent in many of the course learning outcomes, although many courses included group work and collaboration. Interpersonal competencies were mostly mentioned in terms of communication: how to present your results and discuss them. It was pointed out in the interviews that there are strong cultural differences between natural and social sciences. For example, in one of the studied programmes, where students can choose more social-science-focussed or natural-science-focussed courses, the students who choose social-science-focused do not study the natural-science-focused and vice versa. It was mentioned in the interview that 'the two kind of students are different. Most of them prefer to remain in their option and dislike the courses from the other option. There are very few students taking a mixed program using the both kinds of sciences.' Many respondents mentioned in the interviews that it is difficult to get everything important to fit into a limited study programme. In open answers, one remarks '… The difficulty is get just about 'right' amount of it into a specific course within e.g. atmospheric chemistry. …' The person also expressed a need for training on different aspects of sustainability competencies: 'I believe we need some courses on that for the teachers.'

A teaching gap was found in all of the studied competencies (Fig. 6). However, as the sample was small, the difference was statistically significant only in some of the competencies (see Fig. 6 caption for details). The teaching gap was the largest in the basic academic competencies of developing new ideas, making arguments and looking for

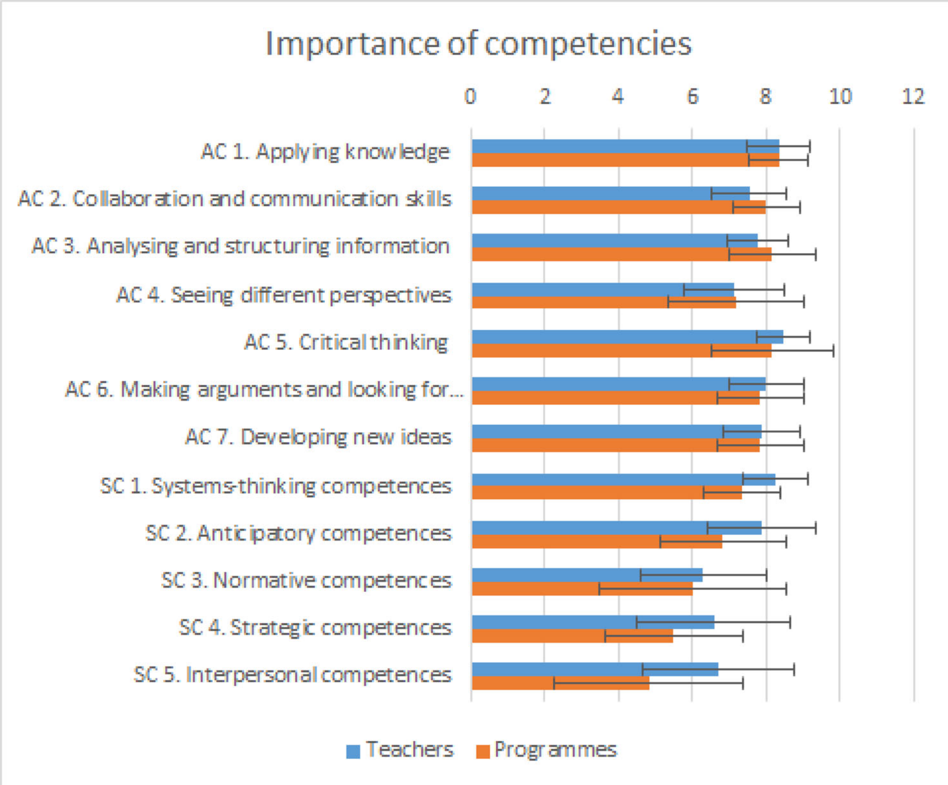


Fig. 4. Importance of competencies. X-axis shows how important on scale 0-9 did the respondents on average rate these competencies for the students to learn. Values are averages of all answers and error bars show standard deviation (+/-1 STD).

solutions, critical thinking and communication and collaboration skills, as well as in the sustainability competencies of interpersonal and strategic competencies. For the programmes, the teaching gap was the largest for the basic academic competencies of developing new ideas and seeing different perspectives, whereas for the teachers the largest teaching gap was found in the interpersonal competencies. The latter one is because the teachers saw the interpersonal competencies more important as the programmes. The teaching gap was the smallest for the basic academic competencies of applying knowledge and analysing and structuring information, as well as for the normative competencies out of the sustainability competencies. In the interviews, the competencies of developing new ideas and seeing different perspectives were seen as something that is not taught or written out in the course learning outcomes, but something the students anyways do while arguing and justifying different choices and when interpreting results.

The teachers had *a knowledge gap* in the competency of making arguments and looking for solutions. For the other competencies the differences were not statistically significant due to the small sample size, but the results indicate that the teachers had a knowledge gap in all of the sustainability competencies and most of the academic competencies. For the programmes, the basic academic competencies were well-known, but an indication of a knowledge gap was found in the anticipatory, strategic and interpersonal competencies out of the competencies of sustainability.

When comparing the atmospheric and the Earth system scientists, some differences were found. The atmospheric scientists were teaching the basic academic competencies a bit more than the Earth system scientists. The Earth system scientists foresaw the sustainability competencies a bit more important than the atmospheric scientists. The basic academic competency of seeing different perspectives was more familiar to atmospheric scientists. It was also more important to them and they taught it more. The strategic competencies, out of the competencies of sustainability, was more familiar as well as important to the Earth system scientists and they taught it more. Both the atmospheric as well as the Earth system scientists had a teaching gap in almost all of the studied competencies. The Earth system scientists found the teaching gap to be the largest in the interpersonal competencies and the atmospheric scientists found the gap to be the largest in the competency of making arguments and looking for solutions (Fig. 7).

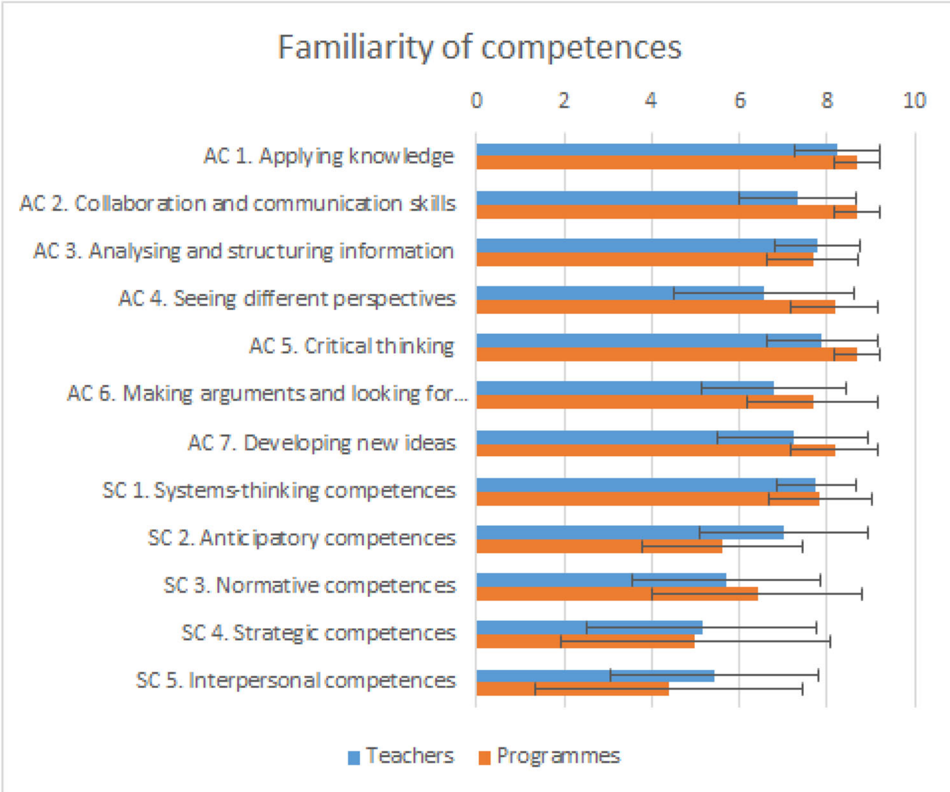


Fig. 5. Familiarity of competencies. X-axis shows how familiar on scale 0-9 did the respondents on average rate the studied competencies. Values are averages of all answers and error bars show standard deviation (+/-1 STD).

4.3. Results on teaching collaboration

All of the studied educational programmes had either ongoing or past teaching collaboration (Fig. 8). Four out of six educational programmes wished to find more partners for the teaching collaboration. Eight out of nine of the teachers had teaching collaboration and seven out of nine wished to find more teaching collaboration. The respondents, both the teachers and the programmes, wished to find teaching collaboration the most from the same field of science or from another field of natural sciences. The teachers also wished to find teaching collaboration from scientists in human or social sciences or cities, communities and other public sector collaborators. The programmes wished to find teaching collaboration from engineering or technical scientists, companies and businesses, or cities, communities and other public sector collaborators. Only few respondents wished to find collaborators from artists, activists and NGOs, or life scientists. Both national and international partners for teaching collaboration were wished for.

In open answers, the teaching collaboration was seen as a tool to expose students to different views. One answerer saw teaching as a burden on research as 'teacher and the departments have to use research funding to keep up given teaching load' and was concerned that '… (our joint course visons) were that we should build a future common top education where our top scientists were teaching. I do not think we really have reached that vision. We have several good but very separate educations.' Another answerer saw collaboration more positively but noted that it is not strategic and planned: 'All collaboration is useful, but in practice some choices have to be made (or often are made more or less accidentally)'.

In the programmes' answers on teaching collaboration one saw that it bring in different perspectives and stated that 'could never be anything but a huge asset', one highlighted the difficulty in coordinating it: 'Experts are often very busy so it is not easy make good timetable for several tasks/experts.', while another explained that it's very common 'we generally have more than one teacher for each subject, that is standard here'.

4.4. Networks in education development

When asked about what networks are important for the education development, the interviewees mentioned the international research networks and international science

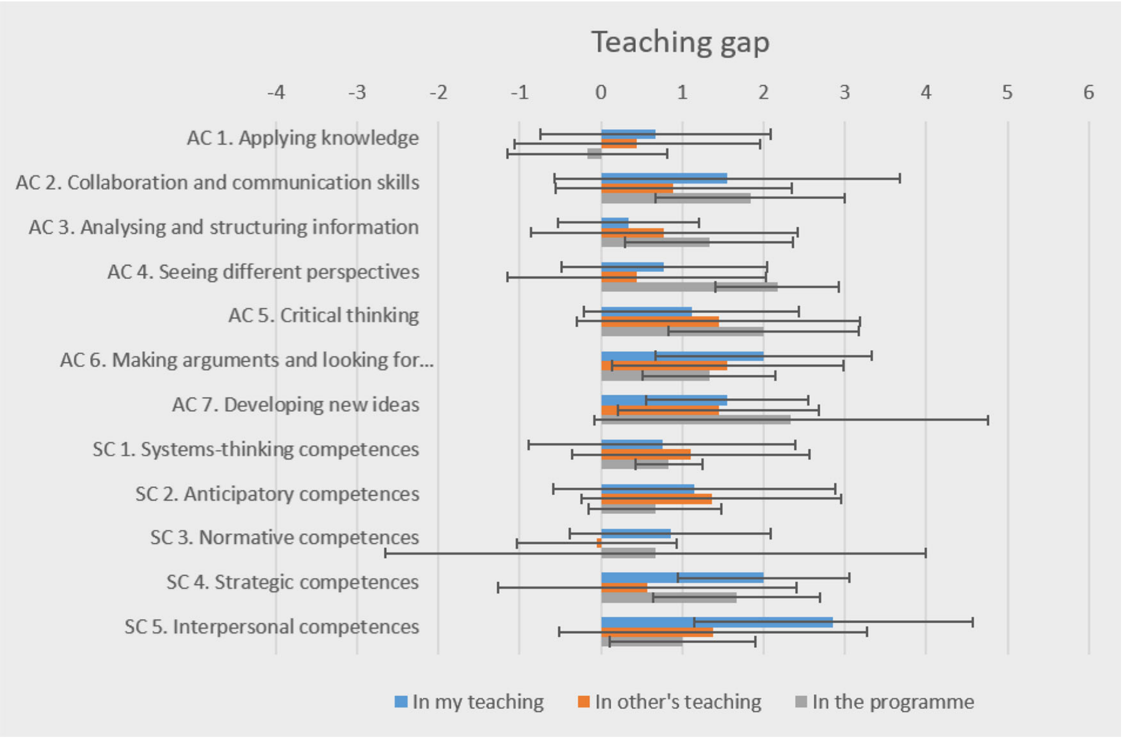


Fig. 6. Teaching gap, defined as the importance minus teaching of the competencies (both on scale 0-9). Error bars show standard deviation. The difference was statistically significant ($p < 0.05$) in cases of AC5-7, SC1 and SC5 (teachers) and AC2-4, AC6-7, SC1 and SC4-5 (programmes).

conferences. One interviewee mentioned that in the scientific networks and conferences they update their knowledge on the latest advances in the field of science, which then feeds into the education. Specifically, ABS network and 'networks providing online education', probably referring to Climate University, were mentioned. None of the interviewees were aware of other studies studying competencies in atmospheric and Earth system education.

4.5. *Future prospects and career opportunities*

For future prospects and career opportunities for their graduates almost all programmes highlighted academic career as an option: 'Stay in research and become a PhD student' or that the degree provides 'a good background if you intend to proceed to doctoral level studies'. In addition, the programme answers included prospect of employment in 'the public and private sectors, both nationally and internationally', 'Meteorological Institutes and Environmental Administration', 'companies manufacturing instrumentation', 'consultancy companies', 'atmospheric/environmental research at universities and research institutes' and 'insurance sector (e.g. risk analysis, catastrophe modelling)'.

The Master in Atmospheric Sciences, University of Innsbruck, is an example of a programme that offers the student career opportunities in private and public sector as well as continuing to PhD studies: 'The career fields for graduates of the master's programme range from meteorological and hydrological services, weather consulting companies, avalanche warning services, environmental agencies, domestic and foreign research institutions and operational centres, to interdisciplinary areas of responsibility where meteorology plays a key role. The Master's Programme in Atmospheric Sciences prepares students for relevant doctoral studies as well as careers beyond the academic area in national and international research institutions' (University of Innsbruck Webpages, accessed 30.4.2020).

4.6. *Expert identity*

Programmes have different focuses on content that can reflect on the experts' identity, as atmospheric sciences is a fairly new field of science and in the degree aims the content and aims vary. We retrieved the programmes' general description, expected learning outcomes, career and future prospects from their webpages (Table 2). Climate or global change, future climates or environmental issues or problems were addressed in 13 out of the

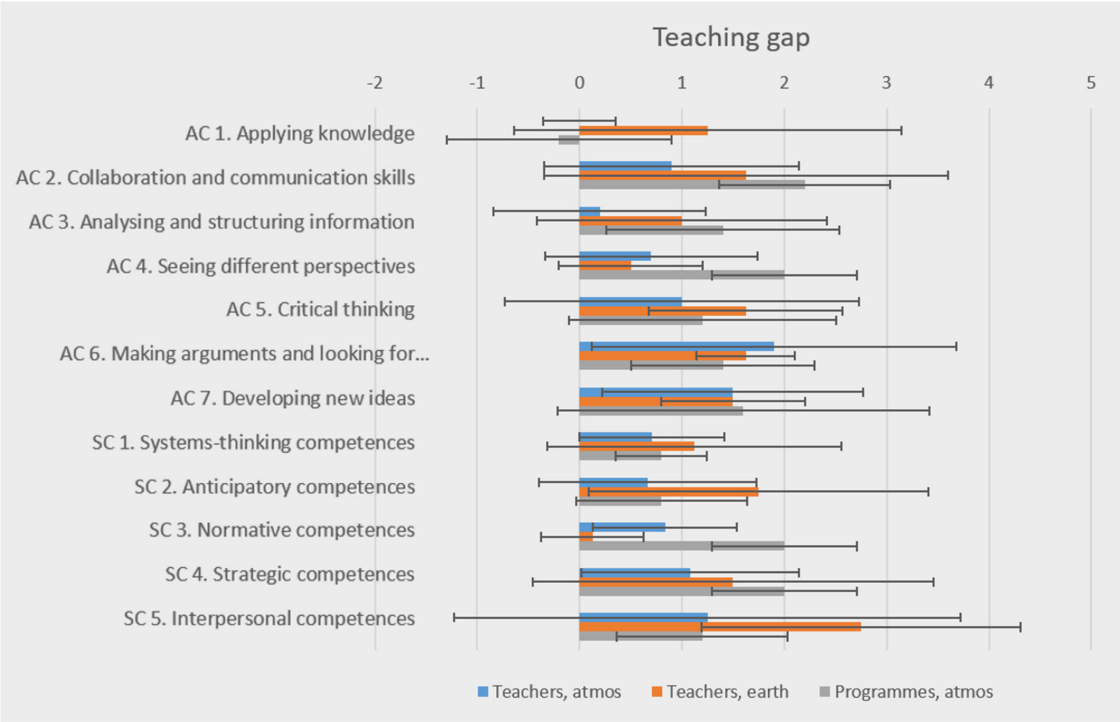


Fig. 7. Teaching gap. Teachers who were identified as atmospheric (atmos) or Earth system (earth) scientists as well as atmospheric degree programmes are presented separately. Error bars show standard deviation. Due to small sample size, most of the differencies are not statistically significant.

selected 17 degree programmes that the questionnaire was sent to. As an example, some masters' programmes in Atmospheric Sciences focus on atmospheric processes and their interaction with land, oceans, ice and biosphere (University of Innsbruck Webpages, accessed 30.4.2020), while another programme expands from weather forecasting, meteorological research and aviation safety and educates also hydrospheric geophysicists as well as chemists and aerosol physicists to work in companies (University of Helsinki Webpages, accessed 30.4.2020).

Some programmes identify clear sustainability aspects in future prospects for applicants: '... students will learn advanced topics in forest ecology and sustainable management for multiple objectives, practical skills, and professional development. Students will interact with academics, private industries, and public agencies through lectures, field excursions, symposia, and workshops. As international programme, we will create an active social network across the world' (Swedish University of Agricultural Sciences webpages, accessed 30.4.2020).

4.7. Climate change expertise

In the interviews we asked about who the respondents see as a climate change expert. The respondents named atmospheric or Earth system scientists with background in meteorology or climatology, who had actively taken part in societal discussion. The interviewees pointed out that climate change is such a wide topic that no-one can master all areas, but expert needs to be a 'specialist in one area and [have] broad understanding otherwise'. Thus, in addition to strong expertise in climate system, also understanding of the societal aspects of climate change was required.

4.8. Societal needs of today

Answering to societal needs of today by academic teaching was clearly seen as science focused: 'Skills that focus on non-science, except Communication, are limited in our teaching.' was stated in one answer, this can also be seen from several degree programme curriculums and learning outcomes that were research career oriented (e.g. University of Lund webpages, accessed 30.4.2020, University of Innsbruck Webpages, accessed 30.4.2020). Outside academia, one clear task was educating future meteorologists doing weather or weather and climate related safety forecasting (e.g. University of Helsinki Webpages and University of Innsbruck Webpages, both accessed 30.4.2020). One respondent noted a bias in view that can hinder educating change makers rather and not just experts 'As a (natural) scientist, I see the bias towards competencies related to ecological sustainability at the

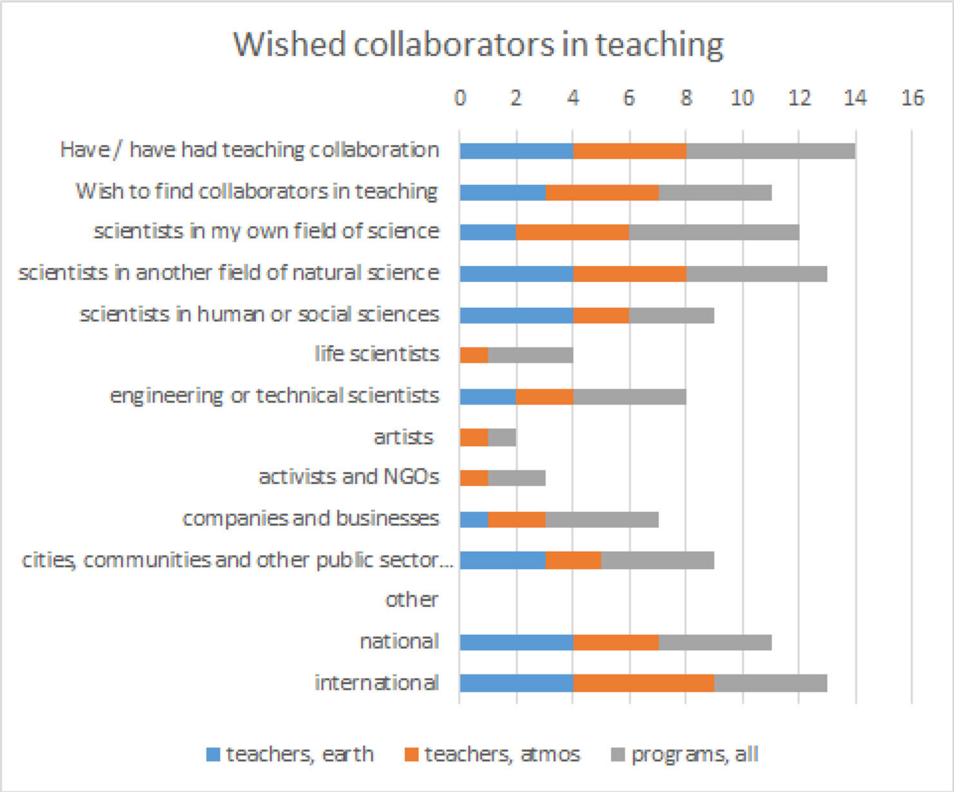


Fig. 8. Teaching collaboration. Teachers who were identified as atmospheric (atmos) or Earth system (earth) scientists as well as degree programmes are presented separately. X-axis is the number each option was chosen, respondents could select as many options as they wanted to.

expense of societal, cultural or economic sustainability. Thus, the competencies fill more the need of information than provide tools for (societal) transformation.'

The programme answers focused that the competencies they teach answer to the societal needs of today mostly on academic competency field 'Scientific/academic competence has been taken into account very well but more general not enough', 'in term of research in climate modelling', 'regarding the academic content I think that the programme provides the students with a very relevant background'. Some of the programme respondents also saw that outcome of their training for societal needs is a 'well-functioning team member' or that the students 'learn what is needed in their later career.'

In the interviews, it was clearly agreed that the studied programmes educate experts, not change makers. When asked about which competencies should be taught more, two out of five interviewees mentioned data science: programming, modelling and data handling. One out of five mentioned 'More general competencies related to sustainable development, circular economy, etc. that are needed in the expert positions in the field (especially in industry). Teaching collaboration is needed'.

5. Discussion and conclusions

With our study we have wanted to initiate the discussion of what are the competences relevant to climate change expertise and which competences are or should be taught in atmospheric and Earth system sciences. We studied if atmospheric and Earth system scientists identify themselves as climate change experts, if the competencies currently taught in atmospheric and Earth system sciences are captured by the concepts of academic and sustainability competences, how the studied atmospheric and Earth system scientists see the competencies they teach answer to the societal needs of today, and what kind of teaching collaboration do the studied atmospheric and Earth system scientists have or wish to have. To probe the questions, we conducted a survey aimed at two European networks of scientists and a number of study programs in atmospheric and Earth system science. The data obtained was limited, so while the analysis is partly quantitative, numerical results should be considered as indicative. The text responses were analysed qualitatively.

We found out that the basic academic competencies were more familiar than the sustainability competencies to the respondents of our survey. This may be explained by the fact that basic academic competencies have been included in curricula for decades whereas sustainability competencies are a much more modern concept. Although the competencies of sustainability have been widely used since Wiek et al. (2011; see e.g. Silvius and Schipper, 2014; Molderez and Fonseca, 2018; Lambrechts et al., 2019), the answers indicate that they are not in use in the atmospheric and Earth system sciences. We foresee here a need to identify and redefine more specifically the climate change related competencies. Especially from the atmospheric and Earth system science point of view, climate change competencies could potentially be more comprehensible than sustainability competencies.

This purpose of this study was to open up discussion and new avenues of research. As such it comes with limitations in representability and generalisability: the results and the limited data we have does not offer a statistically representative view of the European higher education field. We also did not take into account the level of education: all the studied programmes were at the masters level, but the studied teachers were teaching at bachelor, masters and PhD level. Some of the studied competencies, like analysing and structuring information, can be taught at all levels, but some, for example strategic competencies, might be more present at higher level studies. Definitions of teaching gap and knowledge gap were based on two separate Likert scales and should not be taken quantitatively. Also, we studied teachers' and study programme representatives' perceptions on the competencies, which might not be the full picture of the field of education in atmospheric and Earth system sciences.

As future career opportunities the studied programmes highlighted academic career. Continuing to PhD studies and becoming a researcher in Universities, research institutes or private companies were seen as the main future prospect. This might also be reflected in the taught competences and emphasis on academic skills.

The atmospheric scientists in this study did not see themselves as experts on climate change. By defining climate change competencies, we could ease experts as well as students to identify the societal relevance of their expertise. Also, as many study programmes are very packed in content and have different weightings in learning outcomes, concept of climate change competencies could help with prioritisation in the education programmes' curricula design work.

According to our study, the atmospheric and Earth system scientists found the systems-thinking competencies important, but lower importance was given to normative, strategic and interpersonal competencies, which are thematically more closely associated with concepts studied in social sciences (Table 1). Also, scientists from humanities and social sciences, as well as artists, activists and NGO's were less popular choices as collaborators than scientists from other natural sciences (Fig. 8). According to the interviews, there is a strong cultural gap between natural and social sciences. As the multifaceted and crossdisciplinary challenges of today, like climate change, necessitate collaboration, this should also be reflected in the education of future generations. We foresee teaching collaboration as a tool to bring in these competencies into the atmospheric and Earth system higher education. Teaching networks, like ABS network or Climate University, but also science networks, are important forums that can promote such collaboration. In natural sciences, we currently teach experts in natural systems with in-depth speciality and systems thinking does not really include societal aspects – the downside of this educational approach is that natural scientists may hesitate to take part in societal discussion on climate change. This is a drawback for the societal climate action.

Acknowledgement

The authors want to thank Ministry of Education and Culture of Finland (OKM/253/523/2017) as well as Academy of Finland (decision numbers 337549 and 340791) for the funding of this research.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was funded by the Academy of Finland and the Ministry of Education and Culture of Finland.

References

Äijälä, M. and Riuttanen, L. 2019. Co-creating new climate education in Finnish universities. In: *Proceedings of The Center of Excellence in Atmospheric Science*, Report Series in Aerosol Science, No: 226, pp. 138–141. Finnish Association for Aerosol Research, Helsinki, Finland.

Barth, M., Godemann, J., Rieckman, M. and Stoltenberg, U. 2007. Developing key competencies for sustainable development in higher education. *Int. J. Sustain. Higher Ed.* **8**, 416–430. DOI: 10.1108/14676370710823582

Böttcher, F. and Thiel, F. 2018. Evaluating research-oriented teaching: a new instrument to assess university students' research competences. *High Educ.* **75**, 91–110. DOI: 10.1007/s10734-017-0128-y

CAS (Council for the Advancement of Standards in Higher Education). 2015. CAS learning and development outcomes.

In *CAS Professional Standards for Higher Education* (ed. J. B. Wells). 9th ed. Washington, DC.

Climate University Blog. https://blogs.helsinki.fi/climateuniversity/2019/04/18/what-kind-of-new-educational-materials-do-we-need/

Dale, A. and Newman, L. 2005. Sustainable development, education and literacy. *Int. J. Sustain. Higher Ed.***6**, 351–362. DOI: 10.1108/14676370510623847

Franz, D., Acosta, M., Altimir, N., Arriga, N., Arrouays, D. and co-authors. 2018. Towards long-term standardised carbon and greenhouse gas observations for monitoring Europe's terrestrial ecosystems: a review. *Int. Agrophys*. **32**, 439–455. DOI: 10.1515/intag-2017-0039

DiPerna, J. C. and Elliott, S. N. 1999. Development and validation of the academic competence evaluation scales. *J. Psychoeduc. Assess.* **17**, 207–225. DOI: 10.1177/073428299901700302

EC (European Commission). 2015. *European Qualifications Framework*. Online at: https://europa.eu/europass/en/european-qualifications-framework-eqf

Havard, M., Hughes, M. and Clarke, J. 1998. The introduction and evaluation of key skills in undergraduate courses. *J. Further Higher Educ.* **22**, 61–68. DOI: 10.1080/0309877980220107

Jacobson, M. C., Charlson, R. J., Rodhe, H. and Orians, G. H. 2000. *Earth System Science – from Biogeochemical Cycles to Global Change*. Elsevier Academic Press, London.

Kates, R. W. 2011. What kind of a science is sustainability science? *PNAS* **108**, 19449–19450. DOI: 10.1073/pnas.1116097108

Lappalainen, H. K., Petäjä, T., Kujansuu, J., Kerminen, V.-M., Shvidenko, A. and co-authors. 2014. Pan Eurasian Experiment (PEEX)-A research initiative meeting the Grand Challenges of the changing environment of the Northern Pan-Eurasian arctic-boreal areas. *Geogr. Environ. Sustain*. **7**, 13–48. DOI: 10.24057/2071-9388-2014-7-2-13-48

Lambrechts, W., Gelderman, C. J., Semeijn, J. and Verhoeven, E. (2019). The role of individual sustainability competences in eco-design building projects. *J. Clean. Prod.* **208**, 1631–1641. DOI: 10.1016/j.jclepro.2018.10.084

Lauri, A., Ruuskanen, T., Riuttanen, L., Kulmala, M. and Hari, P. 2020. Research-oriented intensive courses foster multidisciplinary atmospheric science. In: *WMO Global Campus Innovations: New Directions for Education and Training, Volume I – New Pegagogical Approaches*. *World Meteorological Organization, Geneva, Switzerland*, pp. 6–17.

Lehtonen, A., Salonen, A., Cantell, H. and Riuttanen, L. 2018. A pedagogy of interconnectedness for encountering climate change as a wicked sustainability problem. *J. Clean. Prod.* **199**, 860–867. DOI: 10.1016/j.jclepro.2018.07.186

Mah, D.-K. and D. Ifenthaler. 2017. Academic staff perspectives on first-year students' academic competencies. *JARHE* **9**, 630–640. DOI: 10.1108/JARHE-03-2017-0023

Molderez, I. and Fonseca, E. 2018. The efficacy of real-world experiences and service learning for fostering competences for sustainable development in higher education. *J. Clean. Prod.* **172**, 4397–4410. DOI: 10.1016/j.jclepro.2017.04.062

Otto, I. M., Donges, J., Cremades, R., Bhowmik, A., Hewitt, R. I. and co-authors. 2020. Social tipping dynamics for stabilizing Earth's climate by 2050. *Proc. Natl. Acad. Sci.* **117**, 2354–2365. DOI: 10.1073/pnas.1900577117

Perkins, K., Munguia, N., Moure-Eraso, R., Delakowitz, B., Giannetti, B. and co-authors . 2018. International perspectives on the pedagogy of climate change. *J. Clean. Prod.* **200**, 1043–1052. DOI: 10.1016/j.jclepro.2018.07.296

Pharo, E. J., Davison, A., Warr, K., Nursey-Bray, M., Beswick, K. and co-authors. 2012. Can teacher collaboration overcome barriers to interdisciplinary learning in a disciplinary university? A case study using climate change. *Teach. Higher Educ.*, **17**, 497–507. DOI: 10.1080/13562517.2012.658560

Rowe, D. 2007. Education for a sustainable future. *Science* **317**, 323–324. DOI: 10.1126/science.1143552

Ruuskanen, T., Vehkamäki, H., Riuttanen, L. and Lauri, A. 2018. An exploratory study of the learning of transferable skills in a research-oriented intensive course in atmospheric sciences. *Sustainability* **10**, 1385. DOI: 10.3390/su10051385

Silvius, A. G. and Schipper, R. P. 2014. Sustainability in project management competencies: analyzing the competence gap of project managers. *JHRSS* **40**, 58. DOI: 10.4236/jhrss.2014.22005

Swedish University of Agricultural Sciences. https://www.slu.se/en/education/programmes-courses/masters-programmes/forest-ecology-and-sustainable-management/

Tuononen, T., Parpala, A. and Lindblom-Ylänne, S. 2020. Complex interrelations between academic competencies and students' approaches to learning–mixed-methods study. *J. Further Higher Educ.* **44**, 1080–1097. DOI: 10.1080/0309877X.2019.1648776

University of Helsinki Webpages. https://www.helsinki.fi/en/admissions/degree-programmes/atmospheric-sciences-masters-programme

University of Innsbruck Webpages. https://www.uibk.ac.at/acinn/studies/master-in-atmospheric-sciences.html.en

Valentini R. 2003. EUROFLUX: An integrated network for studying the long-term responses of biospheric exchanges of carbon, water, and energy of european forests. In *Fluxes of Carbon, Water and Energy of European Forests. Ecological Studies (Analysis and Synthesis)* (ed. R. Valentini). Vol. **163**. Springer, Berlin, Heidelberg, pp. 1–8.

van Dierendonck, D. and van der Gaast, E. 2013. Goal orientation, academic competences and early career success. *Career Dev. Int.* **18**, 694–711. DOI: 10.1108/CDI-01-2013-0003

Wallace, J. M. and Hobbs, P. V. 2006. *Atmospheric Science – an Introductory Survey*. 2nd ed. Elsevier Academic Press, Chicago.

Wiek, A., Withycombe, L. and Redman, C. L. 2011. Key competencies in sustainability: A reference framework for academic program development. *Sustain. Sci.* **6**, 203–218. DOI: 10.1007/s11625-011-0132-6

Zlatkin-Troitschanskaia, O., Pant, H. A. and Coates, H. 2016. Assessing student learning outcomes in higher education: challenges and international perspectives. *Assess. Eval. Higher Educ.* **41**, 655–661. DOI: 10.1080/02602938.2016.1169501