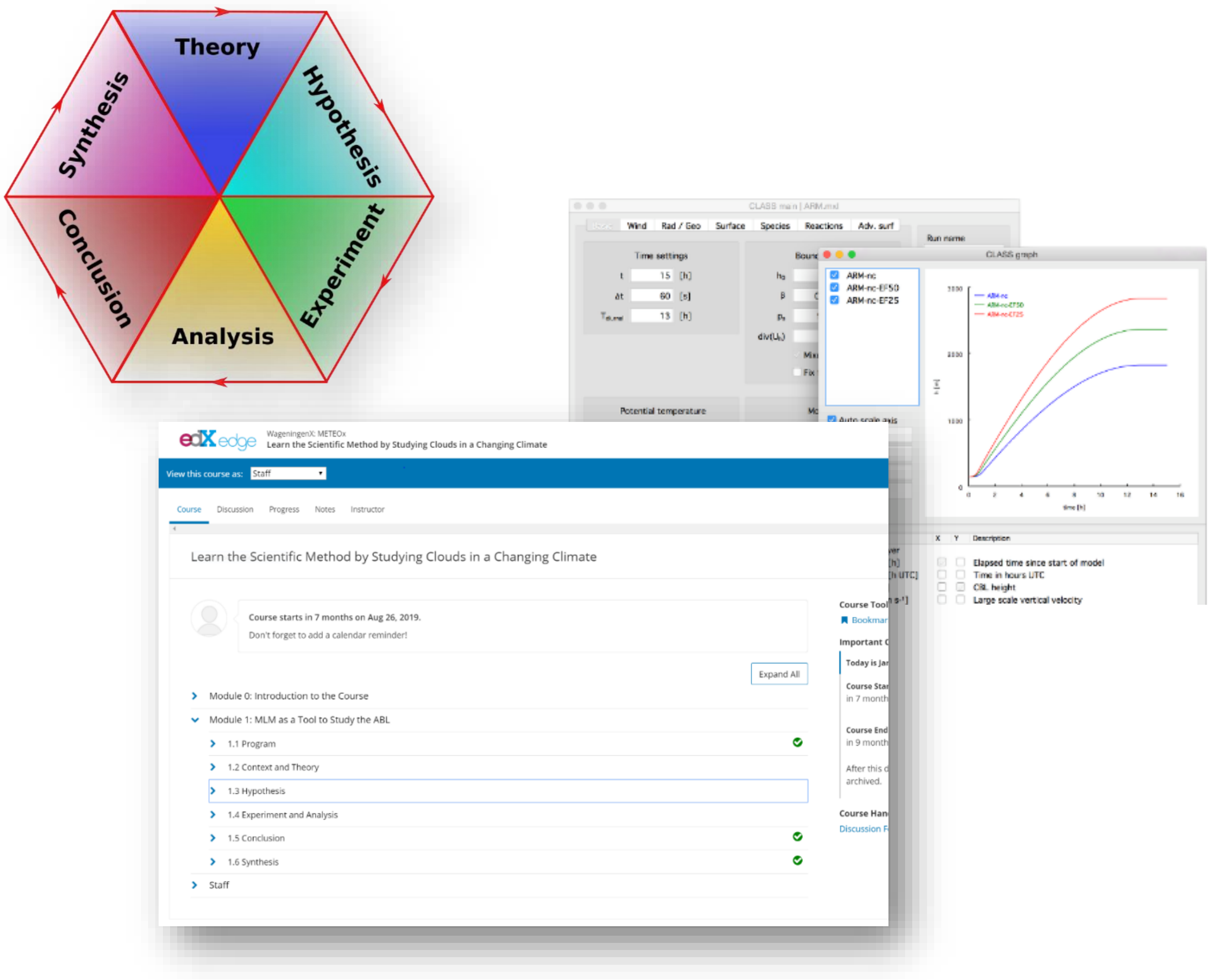
Course manual for the use and re-use of the online course

METEOx - Learn the Scientific Method by Studying Clouds in a Changing Climate



WageningenX: METEOx
Learn the Scientific Method by Studying Clouds in a Changing Climate

Learn the Scientific Method by Studying Clouds in a Changing Climate

Course starts in 7 months on Aug 26, 2019.
Don't forget to add a calendar reminder!

- Module 0: Introduction to the Course
- Module 1: MLM as a Tool to Study the ABL
  - 1.1 Program ✓
  - 1.2 Context and Theory
  - 1.3 Hypothesis
  - 1.4 Experiment and Analysis
  - 1.5 Conclusion ✓
  - 1.6 Synthesis ✓
- Staff

Arnold Moene - Wageningen University

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(version 1, 2019-8-27)

Preface

This document describes the development of an online course that intends to bridge the gap between teaching on the scientific method (and philosophy of science) on the one hand, and scientific practice of students on the other hand. The course was developed as a Small Private Online Course (SPOC) for use in blended education at Wageningen University. However, we hope that the course (or parts thereof) will be of use for other applications as well (PhD courses, summer schools, professionals).

The purpose of the present document is to transfer to the reader as much as possible information and detail on the design decisions that we have taken during the design and implementation phases. We hope that in that way you will feel engaged to use (parts of) the course for your own education. Since the course and all materials therein are made available under the Creative Commons BY-NC-SA license you are heartily invited to re-use the material. In case of any questions, feel free to contact us.

The team that made all of this possible (all at Wageningen University, The Netherlands) consisted of the following people:

Arnold Moene (arnold.moene@wur.nl) Associate professor (Meteorology and Air Quality Group)	• concept • project management • meteorology contents
Jordi Vila-Guerau de Arellano Professor of Meteorology (Meteorology and Air Quality Group)	• CLASS model • scientific method • meteorology contents
Antonija Rimac-van Heerwaarden Online course developer (Meteorology and Air Quality Group)	• concept → reality • development of texts, assignments, figures
Josette Jacobs Assistant professor	• philosophy of science • personal checklist
Bart Gremmen Professor of Ethics in Life Sciences	• philosophy of science
Sanne Mirck Educational designer (Open and online education)	• support in the development stage
Gwenda Frederiks Educational designer (Open and online education)	• support in the development stage • support in the implementation stage • feedback on online didactics and texts
Thessa Mobach Project assistant (Open and online education)	• support in the implementation stage • monitoring of progress
Durk Veenstra Online course developer (Meteorology and Air Quality Group)	• initial concept development • first pilot

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1 Introduction - context

Many societal and scientific challenges relate to systems that are too complex to understand by simple reasoning. The unique path to unravel these systems is to apply the scientific method: posing a question - proposing a hypothesis - experimenting - confirming or refuting the hypothesis. These steps form a closed circle, which is the pillar of modern science. Teaching the scientific method entails that students actively practice these steps. The experimental step can be well performed using simplified conceptual models that contain the essential processes in the system as well as their interactions

Hence, the philosophy of the course is to organize learning and practicing of the generic aspects of the scientific method in a domain-specific context. Whereas the generic part of the course (as well as the structure of the course) can be used in various scientific fields, the domain-specific part needs to be adjusted when the course is used in a different scientific field.

The purpose of this document is to assist prospective instructors both at the level of the design of the course (re-use parts of this course in your own teaching, see section 3) and at the level of teaching (how to use this course in a blended situation, see section 4). For both applications a proper understanding of the design principles behind the course is necessary. Section 2 provides an overview of various aspects of the design of the course.

2 Design of the course

2.1 Original plan and first pilots

The course intends to connect thinking and reflecting about the scientific method with practicing it in a virtual research laboratory (other terms: virtual lab or research tool).

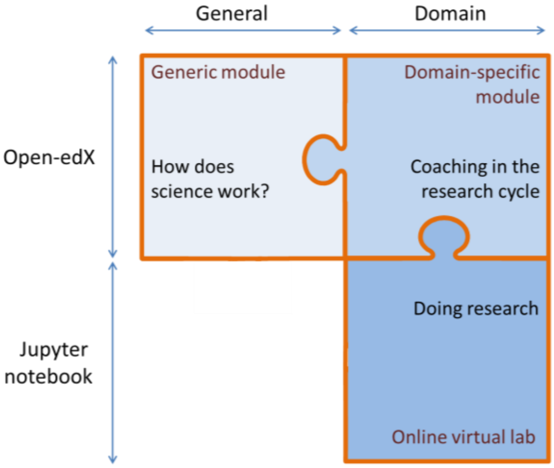

Figure 1 Structure of the course as envisaged in the original plan

Originally, the course was envisioned as a modular course with three distinct parts (see Figure 1): a generic part about the scientific method and philosophy of science, a domain-specific part in which students are guided in practicing the scientific method, and a virtual laboratory that is needed to perform research in. The domain-specific part would be related to cloud formation in the atmospheric boundary layer (lower few kilometres of the atmosphere), and the related virtual lab would be an online version of the conceptual model CLASS that is widely used in our on-campus teaching (Chemistry Land-surface Atmosphere Soil Slab model, see https://classmodel.github.io).

However, in the first pilots with students, it became clear that this setup did not work well, because students were not able to see the connection between the various elements:

- between knowledge about science as an activity and philosophy of science
- between philosophy of science and the scientific method
- between philosophy of science and the knowledge of their own domain

This feedback has made us reconsider the setup radically. We decided to interweave the various aspects much more tightly. We realised that this stronger integration would endanger the intended modularity of the course. However, the course would gain in relevance to the students.

2.2 Setup of the course – overall design

In designing an alternative setup of the course, we have kept our original intention of the course: to use the practice of scientific research to illustrate what we teach the students on the scientific method. But rather than using distinct, loosely coupled modules we redesigned the course along parallel learning paths that could be connected closely at each point in the course. The learning paths were defined as:

1. Philosophy of science: this entails
    a) reflection by the students on their own role in science (through a personal science checklist)

    b) the historic context of the development of the scientific method (research cycle)
2. Methodology[1]: this entails the logic of the research cycle, as well as various generic scientific concepts like causality, feedbacks, validation and uncertainty.
3. Domain knowledge: the meteorology in the lower part of the atmosphere is used as the context in which philosophy of science and methodology are applied.

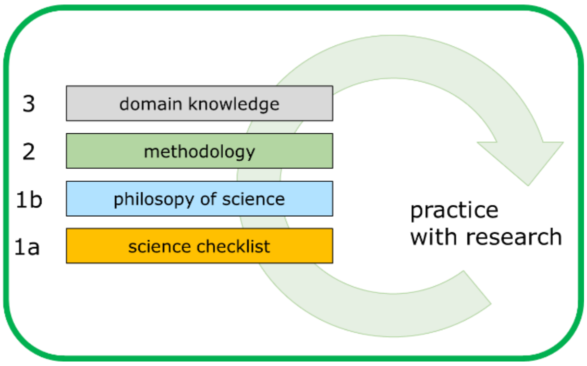

Figure 2 Connection between the learning paths for philosophy (1), methodology (2) and domain knowledge (3) and the training through the use of that knowledge in the practice of scientific research

The knowledge that is acquired in these learning paths is -along the way- applied in the context of a domain-specific research activity (see Figure 2). Hence, the third learning path (domain knowledge) and the practicing in scientific research are interconnected, while the 1st and 2nd learning paths are generic.

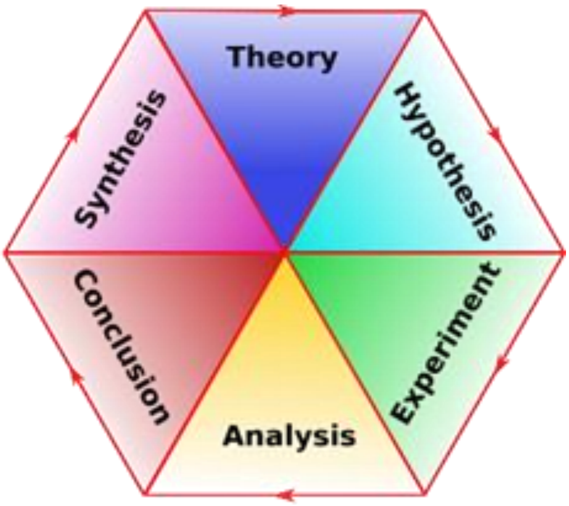

Figure 3 The research cycle is used as an important ingredient of the scientific method, supporting students in systematic research.

The virtual laboratory (already mentioned in section 2.1) is the essential ingredient in the course that enables the student to apply their knowledge about the scientific method in a research context.

The learning paths can be considered to form the backbone of the course from start to end. The short-term structure (at module level) is formed by the research cycle, one of the main ingredients of the scientific method (see Figure 3). The students traverse the research cycle a number times, to become aware of the role of the different steps in the research process. At the same time, the different steps in de research cycle form the motivation and context for the teaching on the aspects of philosophy of science and methodology.

2.3 Setup of the course – module level

In Figure 4 the setup of the course is sketched. The course consists of six modules. In each module three aspects are combined (philosophy+personal checklist, methodology and domain).

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[1] Here, methodology does not refer to things like sampling strategy or statistical analysis of results.

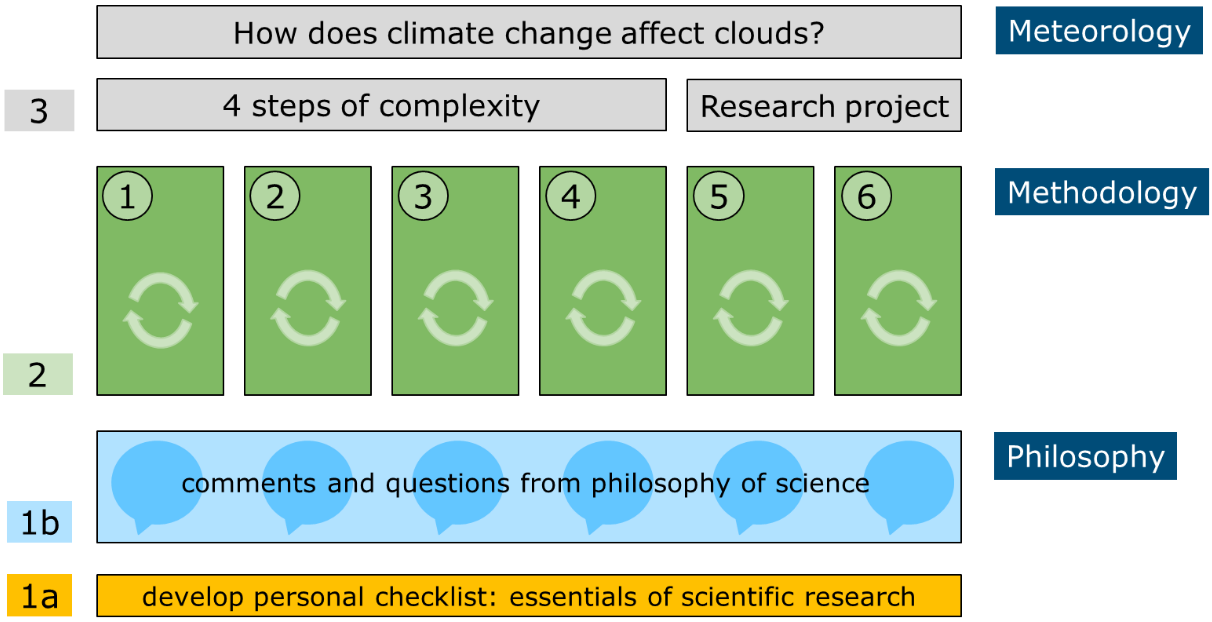

Figure 4 Overview of the structure of the course. The four rows indicate the 4 learning paths. Within each of the first four modules the research activity connects the learning paths. The last two modules are devoted to a research project, consisting of the design of the research (incl. proposal writing) and the performance of the study (incl. report writing).

In the first four modules the students work on all three aspects in an integrated way. In each module they traverse the research cycle which is our interpretation of the scientific method. From module 1 to module 4 the emphasis shifts along the various steps in the research cycle. Furthermore, the degree to which the students are directed in their research gradually decreases from module 1 to module 4.

In the last two modules the students work on their own research project. In module 5 they develop their research project and describe that in a research proposal. In module 6 the students perform the actual research and describe their research and findings in a short report. In addition, they reflect both on their methodology and on their own research process vis-a-vis their personal science checklist.

To enable the students to develop and train their mastery of the scientific method, we provide them with a virtual laboratory in which they can perform their research. Initially, the intention was to develop a new online virtual laboratory, based on a conceptual model that we already use for education. The online laboratory (model) would be implemented as a Jupyter notebook (see https://jupyter.org/) that could be served online from a notebook server (https://jupyter.org/hub). However, along the way it was decided to use the downloadable version of the model (https://classmodel.github.io/) as it turned out that it worked equally well in combination with the online course. The development of the notebook version of the CLASS model continues.

2.4 Learning paths

At the module level the learning paths are tightly connected. However, in order to be able to adapt the course or re-use parts of it, it necessary to have a global overview of each path. Those are given below.

2.4.1 Personal science checklist

The concept of a personal science checklist has been introduced to invite students to reflect on their own role in science. Students gradually grow from absorbers of knowledge to generators of knowledge. But often they are not really aware of this transition, and do not yet consider themselves as scientists-to-be. Through the process of formulating a checklist for themselves we help the students to form a scientist personality.

The contents of the science checklist path is presented below.

Module 0	• Students are introduced to the concept of the checklist and are invited to formulate their first leading principles, purely based on their personal insights at that moment. They have to summarize their ideas expressed in multiple sentences into a bold and clear statement.
Module 1	• Students have to extend their checklist with at least two items that relate to the statement ”Play fair: act with scientific integrity”. We provide the students with a reference to the Netherlands Code of Conduct for Research Integrity.
Module 2	• Students extend their checklist with at least two items, now related to the statement “Science relies on evidence”.
Module 3	• Students extend their checklist with at least two items, now related to the statement “Scientific hypotheses should be tested”.
Module 4	• Students extend their checklist with at least two items, now related to the statement “Progress of science depends on interactions within the scientific community”.
Module 5	• Students reflect, in relation to their own science checklist, on how they operate in process of designing their own research project.
Module 6	• Students reflect, in relation to their own science checklist, on how they operate in process of performing their own research project. They report on this in an appendix of their report.

In each step where students extend their checklist, they share their new items with the other students on a discussion forum. Furthermore, they are invited to review their checklist and possibly rephrase or replace items they added in previous modules.

2.4.2 Philosophy of science

The philosophy of science path provides the historic context of the development of the scientific method. In addition, we introduce a number of concepts that are relevant to the scientific method.

The contents of the philosophy path is presented below.

Module 1	• From rationalism (Plato) and empiricism (Aristotle), via the empirical movement (Descartes, Bacon) to logical positivism. The latter provides the first direct connection with the scientific method as we use it in the course. • The role of the research question and hypothesis in the empirical cycle of logical positivism (observation, induction, verification). Deductive versus inductive reasoning are introduced, in the context of the formulation of a research hypothesis.
Module 2	• Logical positivism is discussed in-depth, including the relationship between the three-step empirical cycle and our six-step cycle. Criticism

	of logical positivism: theory-ladenness of observation, logical soundness of verification, non-observable variables. • The problem of induction: no guarantee that A always causes B. The relation between theory, model and simulation
Module 3	• Karl Popper and critical rationalism. Replacement of the verification principle of induction with the falsification principle of deduction. • Aspects of uncertainty in scientific simulations: location of uncertainty, nature of uncertainty, range of uncertainty, recognized ignorance, methodological reliability, value diversity.
Module 4	• Scientific progress: succession of paradigms (Kuhn), research programs (Lakatos), research traditions (Laudan).
Module 5	• Students design their research project and as such are confronted with the first three steps in the research cycle (theory, hypothesis, experiment (design)) in which various philosophical aspects play a role.
Module 6	• Before the students perform their research project, they are provided with a number of reflection questions related to methodology and philosophy. They are asked to reflect on the design of their research in relation to those questions. They report on this in an appendix of their report.

2.4.3 Methodology

The methodology path teaches the students on the logic of the research cycle and how they can use it to systematically plan and perform a research project. Furthermore, a number of generic scientific concepts like causality, feedbacks, validation and uncertainty are discussed.

The contents of the methodology path is presented below.

Module 1	• The research cycle in six steps. Relationship between theory and models (applied to the field of boundary-layer meteorology). • Properties of a good research question: it identifies the concept, distinguishes relevant research, goes beyond the data, draws attention, allows for surprise, produces complex insights. • Design of sensitivity experiments in relation to the research question. Motivation of model validation.
Module 2	• Scientific research cycle in a three-step cycle (observation, induction, verification) and how this links to our six-step cycle. • Causality as a relation between a cause and an effect. The central role of causality in the formulation of the research question (and as the motivation for most scientific research).
Module 3	• Hypothetical-deductive method as the research cycle that connects to the philosophy of Popper. • From cause-and-effect relations to feedback loops. • Model validation as an iterative process. Guidelines to set up a sensitivity experiment.
Module 4	• Scientific groups and characteristics of variations in scientific research. • Students test what is their own research identity (which of the steps in the research cycle is your favourite step?). • Guidelines to draw conclusions. Guidelines for an effective synthesis.
Module 5	• Students design their research project. This step is systematized as covering the first three steps in the research cycle (theory, hypothesis, experiment (design)) with some link to the last step of the preceding cycle: the synthesis. • In their design students are confronted with decisions to be taken that

	link to what they learned in modules 1 to 4.
Module 6	• Before the students perform their research project, they are provided with a number of reflection questions related to methodology and philosophy. • Students are asked to reflect on the design of their research in relation to those questions. They report on this in an appendix of their report.

2.4.4 Domain-specific part

The course has been developed with a specific research domain in mind: cloud formation in the atmospheric boundary layer. However, the process of doing scientific research is essentially the same across disciplines, although details and customs may vary. Therefore, the domain-specific part can be replaced by an equivalent path for a different domain, provided that for that domain some type of virtual laboratory or research method is available. Because the four learning paths are closely connected, it is important to ensure that also in a newly developed domain-specific part the contents with a certain function end up in the correct location.

One important design principle of the domain-specific path was the use of a unifying research question.

- The unifying research is formulated such that it is too big to be answered within the scope of the course. In this way, we give the students the experience that a small step along the way of answering a big questions is still a step with new insights.
- Next, the problem at hand is reduced to the simplest problem that is on the one hand still relevant for the overall question, but on the other hand simple enough to investigate as a first step (for students with basic knowledge or basic experience with the virtual lab/research tool). With the answer to the research question of module 4 the students should have an answer to the overarching research that is –within certain assumptions– correct.
- Next, in modules 5 and 6 the students continue their quest to investigate the overall research question further, but now challenging one or more of the assumptions/restrictions that were needed for the answer at the end of module 4.

The course has been designed around the central idea that science is in search of understanding the connection between cause and effect (looking for process understanding). The research tool (virtual lab) that the students use when practicing the scientific method should allow for an exploration of those cause-and-effect relationships. Simulation tools have those cause-and-effect relations incorporated and hence the students only need to expose them by experiments. In the case of research by data-analysis, the induction from observed relationships to a conclusion about the underlying processes is the same. However, the student is not certain that indeed the hypothesized process is underlying the relationship observed in the data.

The contents of the domain-specific path is presented below where we have formulated the contents of the modules in a domain-agnostic way.

Module 1	• Theory about the domain at the level that is needed to work on the research question of module 1. Introduction of the research methods used in the domain (observations, simulation, controlled experiments).

	• Formulation of the research question of module 1. • Explanation of the setup of the first experiment, in relation to the research question of module 1. Setup and performance of a number of sensitivity experiments to explore the behaviour of research object. • Validation of the research tool used (at the level of detail that is compatible with the research question of this module).
Module 2	• Theory on the domain at the level that is needed to work on the research question of module 2. • Cause and effect: illustration of what a complete reasoning chain should look like when only the most basic theories can be invoked (this turns out to be a reasoning chain with many more steps than are usually used). The reasoning from cause to effect is linked to the relation between research question and hypothesis. • The context, within the domain, of the research tool that is used in the course: what range of other tools is used (more simple, more complex) and what is their relative merit? The purpose is that students are aware of the status of the tool that they are working with in the course, and realize what kind of questions they can ask about a research tool. • Formulation of the research question of module 2. • Setup and performance of a validation of the research tool used (at the level of detail that is compatible with the research question of this module). • Presentation of the setup of a sensitivity experiment that is designed to answer the research question of the module (the link between question and design is made explicit). Analysis of the sensitivity experiments.
Module 3	• Theory on the domain at the level that is needed to work on the research question of module 3. • Feedback loops as they occur in the domain of study. It may depend on the research tool that is used whether feedback loops are relevant here (if the tool cannot represent feedback loops, the concept cannot be illustrated in the context of the course. Other central concepts from the domain might replace the concept of feedback loops. • Formulation of the research question of module 3. Students reflect on the research question and formulate an additional question + hypothesis. • Uncertainty related to the type of research tools as used in the course. • Students partly design their own model validation (at the level of detail that is compatible with the research question of this module). • Students partly design their own sensitivity experiments (in relation to the research question).
Module 4	• Theory on the domain at the level that is needed to work on the research question of module 4. • Students reflect on what is additionally needed in terms of complexity to come close to an answer to the unifying research question. • Students formulate the research question and hypothesis for module 4. • Students design their own model validation (at the level of detail that is compatible with the research question of this module). • Students design their own sensitivity experiments (in relation to the research question).
Module 5	• Students formulate the research motivation as well as the research question and hypothesis for a research project that brings them closer to a more complete answer to the unifying research question. • Furthermore, they design the method/experiments in which they will use the research tool to answer those questions. • Students write a research proposal that summarizes the motivation, research question and method, with one round of peer feedback.
Module 6	• Students perform their proposed research project.

- Students write a research report that summarizes their findings and answer to the research questions. There is one round of peer feedback.

2.5 Didactics

In the design and implementation of the course a number of didactic choices have been made.

The structure of the course, with the interwoven learning paths, is in itself a conscious choice, based on the feedback from students during the first pilots (see section 2.1). In this way each of the learning paths becomes more relevant as students see how they are connected. Within each learning path, application of the acquired knowledge is trained through exercises that are directly connected to the individual unit (the smallest unit within the course): nearly every unit has at least one exercise in which students need to apply the knowledge presented in that unit. Furthermore, on the scale of a module, the knowledge is put into practice in the research steps that are part of every module (using the virtual lab).

In all modules, mutual exchange between the students forms an essential part. The mutual exchange entails the regular use of discussion fora where students post their thoughts and findings, and provide each other feedback. In addition, in modules 5 and 6 peer feedback on the proposal and report is used as a way to improve the quality of the products and to train the students in their reflective skills. Apart from fostering reflection, it also works to engage the students with the course. The realization of what fellow students are doing, helps students to stay motivated.

In order to make students aware of the structure of the course and the interconnections between different elements, all modules and submodules start with an overview of what is ahead and how this is connected to other parts of the course. At the module level this overview is given in a video in which the overall topic of the module is presented, and the learning outcomes of the module are discussed. The motivation to use a video for this is that it engages the students at the start of the module. Furthermore, at the start of a module, the plan of what is going to come is identical for all students. In contrast, at the end of the module all students have had a different, individual experience. Therefore we use an on-campus (in person) meeting to collect and discuss the experiences, thoughts and questions of the students.

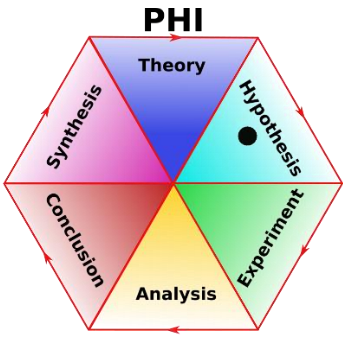

Figure 5 Example of an icon as used throughout the course to indicate which learning path the contents belongs to (PHI, METHOD or METEO) and which step in the research cycle is dealt with (in this case the hypothesis)

Finally, at the lowest level (the unit, a single page in EdX) we use icons depicting the research cycle (see Figure 5). In the icon, the learning path that the provided material refers to is indicated at the top. A dot indicates the active part of the research cycle.

3 Re-use of course components

There are roughly three ways in which this course could be re-used:

- Re-use of one or more of the learning paths in a course with a different course design.
- Re-use of the course design, where the domain-specific part is replaced by another domain-specific part.
- Re-use of individual components: text, figure, model setup, assignments.

The first two options are briefly discussed below.

Please note that much of the material used within the course is provided online at https://scientific-method-course.github.io/.

3.1 Re-use of learning paths

In order to re-use an individual learning paths one needs to identify which parts of the text and assignments relates to that given path. In the online course the different paths are indicated with icons (see Figure 5). As an additional input we provide a spreadsheet in which for each part of the text (at sub-unit level) we indicate to which learning path it belongs (scientific_method_paths.xlsx, available from the website mentioned above).

Once located, those text fragments need to be copied from the online course to another medium (or another EdX course). In our experience, copy and past from the browser works quite well. For the figures embedded in the pages we provide an additional source: a zip-file with all figures is available at the above-mentioned website.

When isolating a single learning path from the course, one should keep in mind that the for the current implementation the four learning paths where developed alongside. As a result, some cross-talk may exist between different learning paths. Hence, it may be necessary to edit some parts of the extracted learning paths to make them independent of the rest of the course.

3.2 Re-use of the course design

When re-using the course design we assume that all learning paths are kept intact, except for the domain-specific learning path. In section 2.4.4 a generic description of the domain-specific learning path is given, module-by-module.

Before a new domain-specific learning path can be designed, one first should decide on:

- the research tool that the students will use to practice their research with;
- on the unifying research question that connects the six modules content-wise.

The research tool is put first on purpose, since most likely finding a proper research tool (virtual lab) will be the limiting factor. Once the tool has been decided on, the potential research questions will follow.

3.2.1 Research tool (virtual lab)

In section 2.4.4 we already stated that the course has been designed around the central idea science implies a search for cause and effect-and-effect relationships. The research tool used by the students in the research process should allow for an exploration of those cause-and-effect relationships. Simulation tools based on a description of the underlying processes have those cause-and-effect relations incorporated and hence the students only need to expose them by experiments. In the case of research by data-analysis, the induction from observed relationships to a conclusion about the underlying processes is the same. There are however two main differences: first, in data-analysis one does not have full control over de independent variables, and second, the student cannot be certain that the hypothesized process is indeed underlying the relationship observed in the data.

In the table below we list a number characteristics that need to be considered when selecting the research tool for use this course.

Characteristic	Considerations
Independent of time and location	• The research tool is to be used in an online course, hence the research cannot take place in a physical location. This excludes experiments in a lab or outdoors. • One could envision a research project in which the data collection is done in the physical world, whereas the data-analysis is done using an online tool, or with an offline program on the student's computer.
Type of research	The research tool should allow for research into causal relationships. • Simulation tools allow for controlled experiments with clearly identifiable independent variables. The underlying causal relationship (however complex) are known. • Data-analysis allows for exploration of relationships between variables which may confirm or refute hypotheses. However, the underlying causal relationship may not be known.
Time per experiment	Since students make use of the research tool repeatedly, the wall-clock time per experiment should be limited (order of seconds or at most minutes). In that way the students have sufficient opportunity to get accustomed to the tool. Furthermore, it makes sensitivity experiments feasible.
Complexity - dimensionality	To focus the attention of the students it is advised to use a low-dimensional research tool (in terms of space and/or time). Although the real world is 3-dimensional and time-dependent, proper process understanding is often aided by a reduction of the number of dimensions (equilibrium models, 1-dimensional time-dependent models). This relates in particular to the ability of students to build a reasoning for how the causal relationship they are after could work.
Complexity – number of processes	To focus the attention of the students it is advised to use a research tool that incorporates a limited number of processes. The number of processes should be sufficient

	to obtain interesting and unexpected results (including interactions between processes). On the other hand, the number of processes should be small enough so that students are able formulate a clear reasoning that connects the cause to the effect.
Complexity – gradual increase	The research tool should allow for a gradual increase of the complexity while the students traverse from module 1 to module 4. This growing complexity could be related to: • the number of processes or variables involved, • the dimensionality (from equilibrium to non-equilibrium), • the complexity of interactions (from cause-and-effect relations to feedbacks) Another way to vary the attention in modules 1 to 4 would be look at different aspects of the problem at hand. Then the research tool should allow to investigate a number of different aspects (variables, processes, scales), leading to answer to related sub-questions.
Open source	If the course is intended to be open for students beyond your own institution, the research tool around which your course is built should be freely available. Where relevant, the same should hold for the underlying technology (e.g. Python (free) versus Matlab (not free)). An additional advantage is that, with the use of open source software, the student is able to use the tool in their further study programme or their professional career (they are allowed to take it with them).

An important aspect in the table above is that research tool should not be too complex. Apart from practical considerations, the main argument for that is that simpler representations of reality may lead to a better conceptual understanding of the students. At the same time, the students should realize that what they are studying *is* an overly simplified representation of reality.

3.2.2 Unifying research question

The unifying research question functions as a permanent point of orientation. Every small research activity along the way aims to contribute in some way to an answer to that question. There are a number of design criteria to take into account with respect to this leading research question.

To ensure that there is sufficient scope for the students' own research in modules 5 and 6, the unifying research has to be formulated such that it is too big to be answered within the scope of the course first four modules. Preferably, even the research in modules 5 and 6 should not yield a final answer. In this way, the students are given the experience that a small step along the way of answering a big questions is still a step with new insights.

Next, the research question at hand should lend itself to be answered in smaller steps. In the present implementation of the course, the intermediate steps towards a full answer were steps of increasing complexity (adding additional processes along the way). This way of subdividing the research implies that –as far as the research tool allows–

there is always additional complexity to be added (in modules 5 and 6, and beyond). An alternative scenario would be to divide the main question in multiple sub questions. Those sub questions then would be answered in the first four modules, so that after module 4 there is an answer to the overall question. In this scenario the challenge would be to leave sufficient room for additional research by the students in module 5 and 6. This could for instance be done by rephrasing or extending the overall research question after module 4.

Before deciding on the unifying question, one should explore what exactly would be the formulation of the research questions for each of the modules. The question for the first module should be the simplest possible problem that is on the one hand still relevant for the overall question, but on the other hand simple enough to be investigated as a first step. For the first module one should keep in mind that students may only have basic knowledge on the topic (provided in prior courses or in this course) and basic experience with the research tool. The research questions for the subsequent modules should build on the knowledge from the prior module, and the should increase in complexity of completeness. Furthermore, the answers to the subsequent research questions should ideally converge to an increasingly correct –within certain assumptions– answer to the overall question.

3.2.3 Implementation at the module level.

At the module level, the main challenge is to make the connection between the domain-specific content and the topics of the other learning paths. In section 2.4.4 we have identified which topics and activities are located in which module. But the partitioning of material within the module requires an extra step. The main determining factor for that is that the domain-specific material should follow the steps of the research cycle: theory, hypothesis, experiment, analysis, conclusion and synthesis.

At the lowest organizational levels, submodule and unit (a single page in EdX), the location and ordering of the domain-specific material is influenced by the other learning path and the exact contents of the domain-specific material. In the end, after the material from the different learning paths has been combined, the course should tell a coherent story.

Please note, that the current implementation the four learning paths where developed alongside. As a result, some domain-specific references may have leaked in the generic learning paths (checklist, philosophy and methodology). Hence, it may be necessary to edit some parts of the generic learning paths to make them match with the new domain-specific content.

4 Teaching the course

The course has been implemented in EdX-Edge to allow the course to be used both within the university and outside (as part of education at other universities, summer schools etc.). The work load of the course is 3 EC (84 student hours), roughly divided equally over the six modules.

At Wageningen University the course is used within a blended course that is offered to 3rd year BSc students and 1st year MSc students (as an optional course). Content-wise the students are assumed to be familiar with the contents of two 2nd year BSc courses (to defined the starting level for the online course). Both for the BSc students and the MSc students, the course is primarily intended to improve their preparation for their BSc-thesis or MSc-thesis.

In the Wageningen system the course runs in a 6-week period (with two additional weeks at the end which are used for exams and exam preparation for regular courses).

The online course is supported by a weekly class-room session of about 1 hour. This meeting is mainly devoted to continuing some of the online discussions and clarifying certain concepts. Furthermore, practical and organizational issues can be discussed. Since the EdX course only contains the contents of the course, the organizational aspects of the course are dealt with outside of EdX. To that end, the course is supported by a Brightspace course (the standard Electronic Learning Environment at Wageningen University). Brightspace is used for communication with the students about practical matters related the course (both through e-mail and via a discussion forum). Furthermore, the Brightspace course is used to hand-in the proposal and report, and for the administration of the grading.