Active learning in environmental science: "Design your own vegetation model!"

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Introduction

Vegetation models are complex process-based models that integrate a broad range of biophysical processes, from photosynthesis at the leaf level up to vegetation dynamics at the ecosystem level (Prentice et al., 2007). They are often used to quantify and predict changes in carbon and water cycling, as well as vegetation cover, under current and future global change. These models are highly complex and learning about their components, structure and practical use can be a challenging task for students. An active learning exercise can be a great educational tool that will facilitate the students to get a better grasp on the structure and functioning of these types of models.

In this paper I present the results of an active learning intervention in a master level course in the field of environmental sciences. I start by discussing the context, motivations and goals for such an intervention, share the specific setup and learning activities, and I end with sharing the outcomes, conclusions and future recommendations.

Context

The *Ecosystems, Climate and Climate Change* (ECCC) course is a master level obligatory course for students that are enrolled in the MSc program in Geography and Geoinformatics, and the MSc in Environmental Sciences at the University of Copenhagen (UCPH). The course focuses on the relation between terrestrial ecosystems and global climate systems across various temporal and spatial scales, as well as in the context of future climate change. The intended learning outcomes (ILOs) (Biggs, 2014; Biggs & Tang, 2011) include gaining knowledge on the status of climate change research, accounting for the relations between climate, ecosystems and land use, based on relevant datasets and models, as well as describing and interpreting ecosystems and vegetation dynamics (see Appendix A for a complete list). The course lectures traditionally consist of a teacher presentation (~2 hours) on the theory, followed by a practical exercise session (~1 hour). Students can come from a relatively broad scientific background and are recommended to have a BSc in Geography and Geoinformatics, Ecology, Physics or equivalent. The course has an ECTS rating of 7.5 and the official capacity is 25 students. This capacity is often exceeded, and 44 students were enrolled when I participated in the teaching in the first block of the academic year 2024/2025.

For my lecture I introduced vegetation models and how they are used in environmental science. After a general introduction of what vegetation models are, students learned about the different processes used in these models, how they are integrated and how the models are applied to answer research questions. The lecture ended with an introduction of a specific vegetation model, which the students used for the practical and the final exam project. This lecture formed a key element in the ECCC course, as it integrated several of the processes the students were introduced to in the previous lectures (e.g. photosynthesis, plant-water relations, land-atmosphere fluxes, biogeography, climate change). The ILOs for this lecture were: (1) understanding how vegetation models work by building connections between different ecosystem processes, (2) identifying research questions that can be addressed with a vegetation model, and (3) applying a vegetation model to study climate change impacts for a given site.

Motivation and objectives

The theoretical part of each lecture is designed as a classical teaching situation in which the teacher presents the students with information on the blackboard and slides. The students take a more passive role by consuming the presented information, and often the only form of interaction happens during the occasional class questions the teacher may pose. This form of passive learning elicits a low engagement of the students with the presented material, which may limit the student's understanding and retention of the course content. It is also risky, as some students may lose the thread in the teacher's narrative and are unable to follow the rest of the lecture. Therefore, this method is not an optimal approach to reach the ILOs of the course in general and my lecture specifically, both of which span various levels of Bloom's learning taxonomy (Anderson & Krathwohl, 2001).

Interrupting the traditional teacher lecture by including an active learning exercise, can help to alleviate these limitations and risks and to support the ILOs more effectively (Biggs, 2014). The structure of this activity roughly

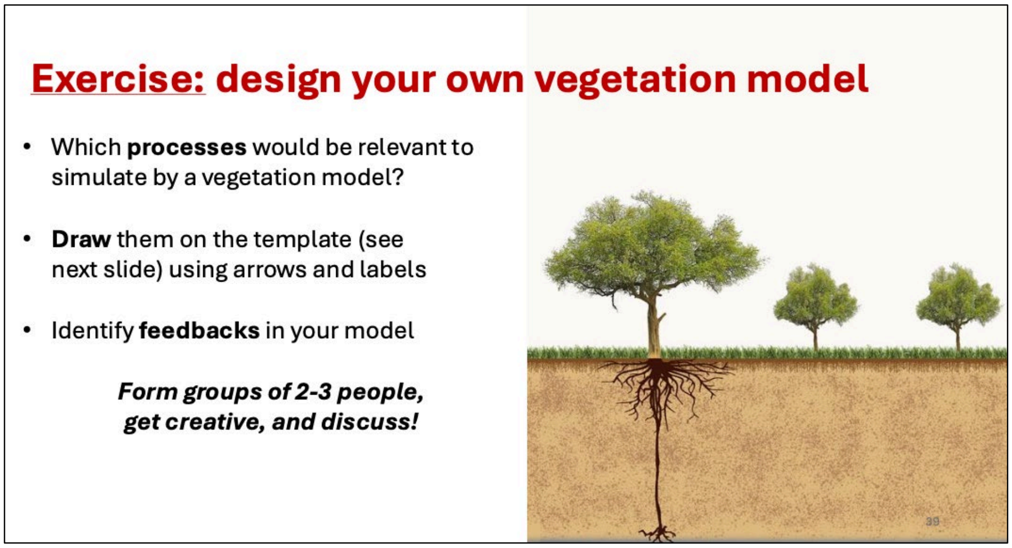

Fig. 1. Instruction slide for the active learning exercise. Instructions are given on the left and the empty ecosystem template is shown on the right. The template was also given as a full-page slide on which the students could draw.

follows the Theory of Didactic Situations (TDS) model, which is based on the principle that teaching and learning is not simply a question of the teacher pouring knowledge into a group of passive students, but it is about creating the space for students to work independently with a given set of data, yet within the framework that was planned by the teacher (Artigue et al., 2014). This model is considered a best practice for university teaching by the Department of Science Education at UCPH.

The goals of my active learning intervention, described in more detail in the next section, were to engage students more in class and let the students create connections between the different parts of the course that were introduced up to this point, thereby introducing teaching/learning activities that are at the highest level of Bloom's taxonomy for higher order learning (Anderson & Krathwohl, 2001). These goals help to solve the problem of teaching ecosystem models of high complexity to master students with little modelling background. My personal pedagogical development motivations to do this intervention were to experiment with new ways of teaching, and to get a better insight in the background of the students and their knowledge so far.

Active learning intervention

The active learning intervention consisted of an exercise in which the students were asked to build a conceptual vegetation model from scratch. Students were asked to reflect and discuss with their neighbors (groups of 2–3 people) on the

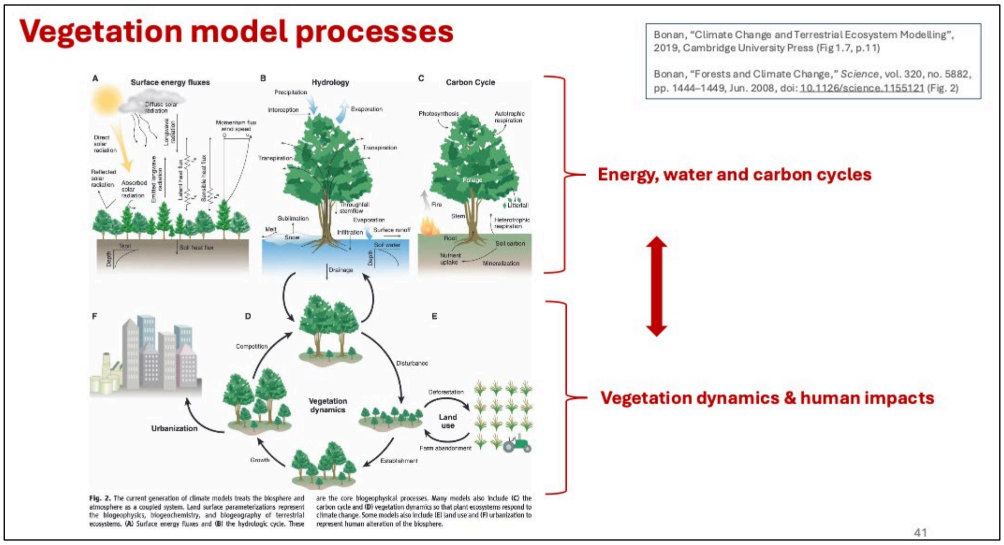

Fig. 2. Institutionalization slide, containing the answers for the "Design your own vegetation model" exercise. Figures were taken from Bonan (2019).

different physical, biological and ecological processes that would be relevant to simulate with a vegetation model. An empty ecosystem template (Fig. 1) was provided on which the students could draw the results, using arrows and labels. For example, photosynthesis would be an arrow pointing into the tree leaves. The students were also asked to think about any possible feedbacks in their conceptual ecosystem model.

The students had about 20 minutes to do this exercise, and after that they were asked to share their results with the rest of the class. I drew all answers on the blackboard, using different colors for different types of processes (e.g. blue for everything water related, green for everything carbon related, and so on). I also gave some feedback on the results, e.g. whether a given process is usually included in current vegetation models. This quickly turned into a messy diagram, highlighting the complexity of these models. Finally, I presented a more structured slide, which provided an overview of all processes considered in a typical vegetation model, neatly divided into processes related to water, carbon, energy and vegetation dynamics (Fig. 2; Bonan, 2019).

The main ILO for this exercise was identifying, prioritizing and integrating different ecosystem processes to create a conceptual vegetation model. This exercise therefore also stimulates the students to build connections between several course modules that they followed so far, although at a relatively shallow conceptual level. This aligns with the first ILO for this lecture, mentioned in the "Context" section before: *building connections between different ecosystem processes*.

Outcome and evaluation

Student participation was overall high. Nearly all students were actively engaged in relevant discussions with their peers during the reflection and discussion part. The foreseen duration of this phase was also suitable, as the discussions started to fade out by the end of the 20 minutes. During the answering phase, many student groups presented their results by suggesting processes to add on the blackboard. Some groups were more active in this than others, and I had to request students that hadn't contributed to chime in as well. The quality of the answers was high as well. All relevant ecosystem processes were covered by the end of the answering phase, including processes that are not usually represented in present-day vegetation models[1].

After the exams a questionnaire was sent out to the students, asking their opinion on this exercise. Out of the 44 students that were enrolled in the course, 10 filled in the form. The students that participated in the questionnaire were overall positive about this exercise, as 80% of them agreed that the exercise was relevant and useful to better understand vegetation models (Appendix B). Most students (70%) felt like they learned something in each part of the exercise, and especially in the phase where students could share their ideas with the class. One respondent found the exercise too easy and not useful and would have preferred a classical teacher lecture instead. No students added any additional comments. All survey questions and answers can be found in Appendix B.

I end this paper with a few suggestions for a future adaptation of this exercise, presented in decreasing order of importance. *First,* one could consider implementing different ways of letting the students share their ideas. For example, one could let all students come to the blackboard, let them draw their ideas all together, and then discuss them in class. Another idea would be to form larger groups, let each group design and present their model on a large sheet of paper, and have the teacher moderate a class dialogue between the students on comparing the model versions (Scott et al., 2006). Doing so would follow the TDS model more closely by including a validation phase, which was missing in this exercise (Artigue et al., 2014). *Second,* I did not spend much time on discussing the feedback loops in the designed model. This topic was dealt with later in the lecture, but I did not refer back to the exercise. It would be good to either discuss ecosystem feedback loops more explicitly or remove this topic

[1] Unfortunately, I forgot to take a photo of the blackboard!

from the exercise altogether, as it is discussed later on. *Thirdly,* the student groups consisted of class neighbors. One could consider of randomizing the group formation process to stimulate more interactions inside the class and to mix up students with different backgrounds. However, these three suggestions may take additional time, and the space may not be convenient for letting the students move around much (like it was in this case). Additional time could be created by shortening the practical session or reducing other parts of the lecture (e.g. lowering the number of model case-studies). *Finally,* I did not supply the students with any printed ecosystem templates, assuming they would draw it on their computer or copy the template to a piece of paper themselves. The result was that many students didn't draw anything at all. It would be helpful to provide this in the future, as drawing ideas on a paper involves a higher level of engagement and can aid with the task of designing a model.

A more experimental idea for this lecture would be to move the practical session to the beginning. After a short introduction, the students can be instructed to directly start working on the model simulations, without really knowing what is going on, i.e. working with a black box model. In the following theoretical part, the students can then be asked to reverse engineer what could be going on in the model, connecting the model inputs with the outputs by applying what they remember from previous modules. This idea is still similar to the exercise presented in this paper, but it shifts its focus more towards *inductive learning*, as the students immediately start working with the material and fill in the blanks during the process (Prince & Felder, 2006).

Concluding remarks

The implemented active learning exercise had an overall positive impact on student engagement and supported the ILOs more effectively than a purely traditional teacher presentation. The teaching/learning activities in this exercise aligned more closely with the ILOs of both the course and the specific lecture, following the framework of constructive alignment (Biggs, 2014). Creating the space for students to reflect, discuss, draw and synthesize previous elements of the course into their own vegetation model engages them more with the course material, increases retention, and helps them to identify potential gaps in their knowledge. This teaching/learning activity can be further adapted and optimized in the future and used as an integral part in the teaching of complex models in general, and ecosystem models specifically.

References

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Appendices

Appendix A: content and learning outcomes for the Ecosystems, Climate and Climate Change course

Information taken from: https://kurser.ku.dk/course/nigk17013u

Content

The focus of the course is on the relations between terrestrial ecosystems and global climate systems. Seen in a historical and present perspective as well as on a temporal and spatial scale, the interactions between climate and ecosystem are put in perspective of the ongoing and future climate change. Further, the course explains how models and databases are used to develop future climate scenarios and reconstruction of previous climate conditions, as well as the anthropogenic role in the present changes in climate.

Learning Outcomes

Knowledge
Status of the research in climate changes, models for projection of climate development and the content of greenhouse gasses in the atmosphere. Natural and anthropogenic forcing of climate. Theories and concepts on ecological climatology, terrestrial ecosystems, the global climate system, climate variations, Milankovitch cycles, greenhouse gasses, annual variations in relation to the regional climate and the effects hereof, the relation of vegetation dynamics and CO_2 balance, climate models, climate predictions.

Skills
- Account for the changes in climate in recent times
- Account for the relations between the climate and the content of greenhouse gasses in the atmosphere
- Account for the relations between the climate, ecosystems and land use in different climate zones
- Identify and explain the interaction between atmospheric circulation and radiation/energy balance and the relation to the global climate zones.
- Explain and discuss Global weather phenomes as El Niño and NAO and their influence on the weather in the northern Atlantic and Europe.

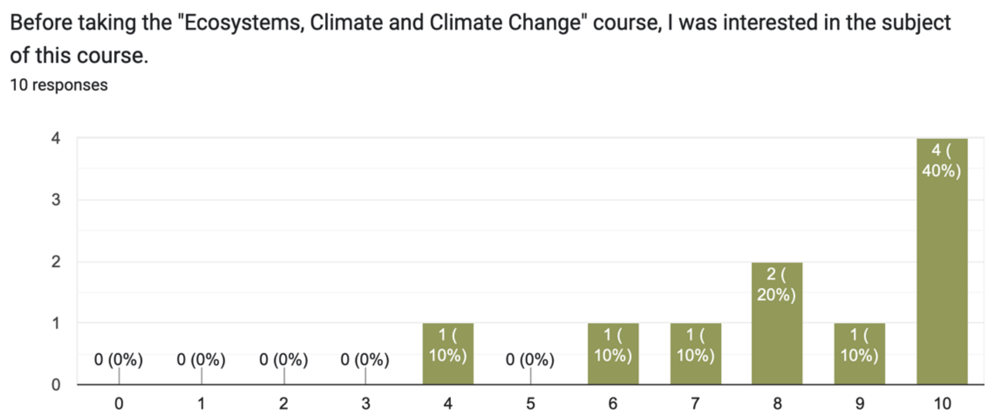
- Identify and explain spatiotemporal variations in permafrost processes and ice cover extent in the north Atlantic – causes and consequences.
- Identify and explain variation in radiation balance and wind climate at different surface types.
- Explain and discus photosynthesis, evapotranspiration and energy balance in relation to spatiotemporal variation in the vegetation and land use.
- Describe and interpret ecosystems and vegetation dynamics – carbon budget, net primary production, biogeography and vegetation modelling.
- Identify and describe the carbon exchange I relation to agricultural areas and other ecosystems under human influence and the problems caused by deforestation, desertification and change in land use.

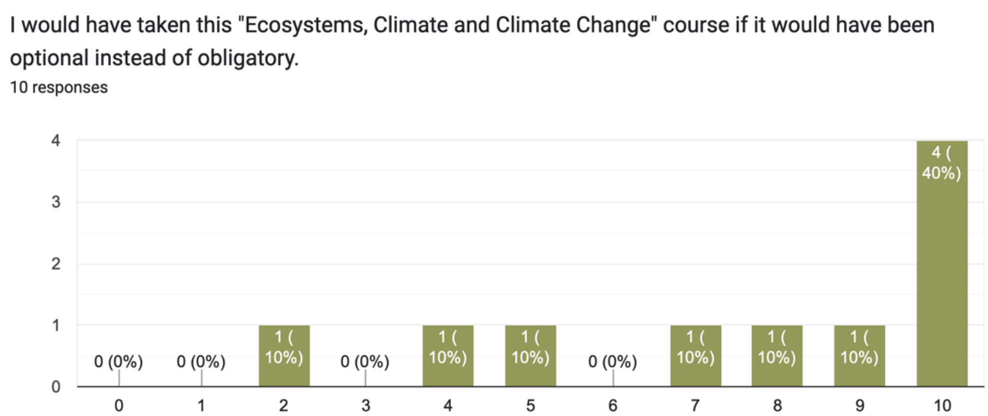
Competences

- Ability to communicate knowledge about the climate change problem in a written assignment.
- Insight in the phenomenon of climate change and ability to distinguish between anthropogenic and natural causes.

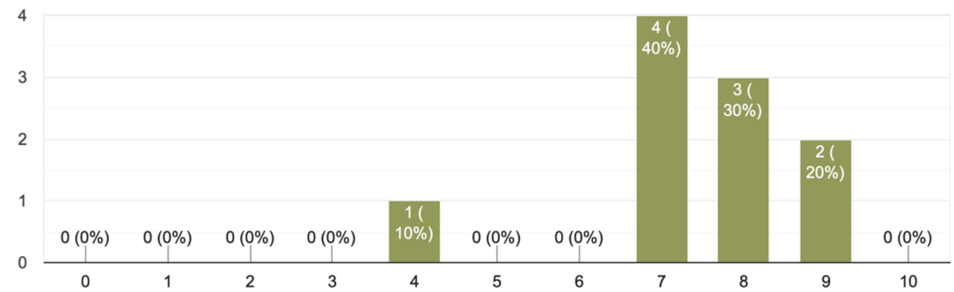
Appendix B: student survey results

All questions were formulated as a statement where students indicate their agreement with values from 0 (“Strongly disagree”) to 10 (“Strongly agree”). Out of the 44 students that were registered for the course, 10 filled in the survey. In what follows I show the questions and the distribution of answers to each. No respondents added any additional comments in the open comment field.

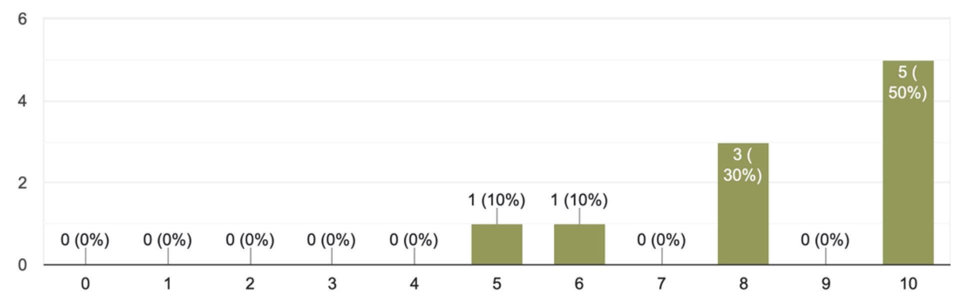




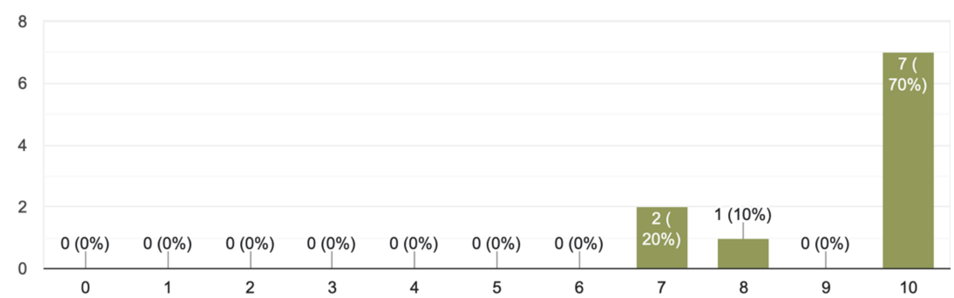
After taking this course, I can say that it matched my expectations (high or low) overall.
10 responses



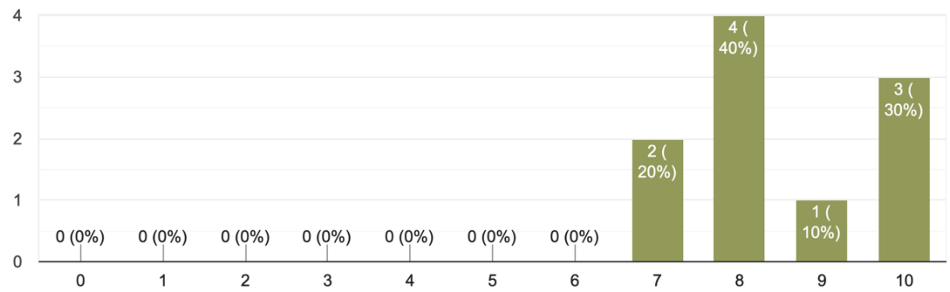
I found the specific module on vegetation modelling (taught by Wim) relevant for this course.
10 responses



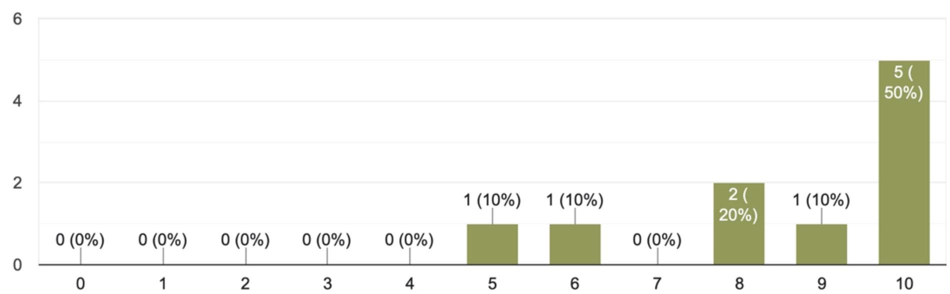
I remember the class exercise on "Design your own vegetation model", where we collected all kinds of ecosystem processes and drew them on a template...s the instruction slide that was shown in class:
10 responses



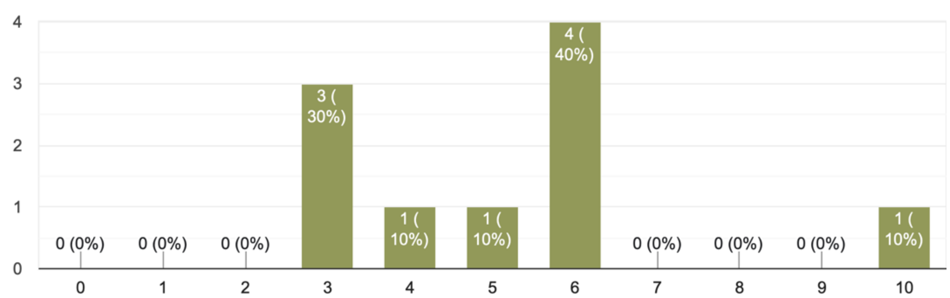
This class exercise was clearly introduced and I knew what was expected from us.
10 responses



I felt that I had enough background knowledge to do this exercise
10 responses

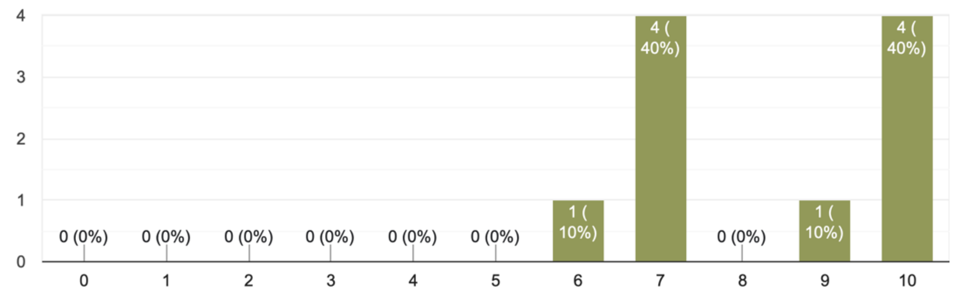


This exercise was too easy.
10 responses



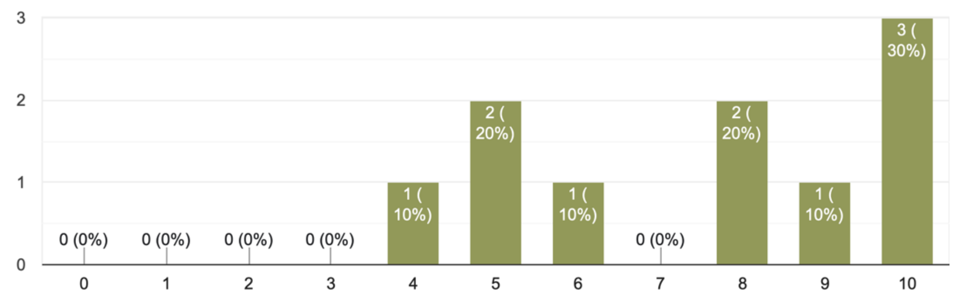
I had enough time to do the exercise: i.e. to discuss with my neighbor, to draw the processes, and so on.

10 responses



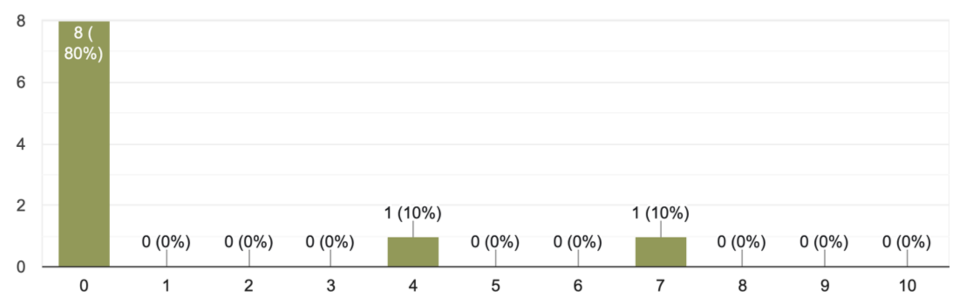
I felt comfortable to share my results with the rest of class.

10 responses

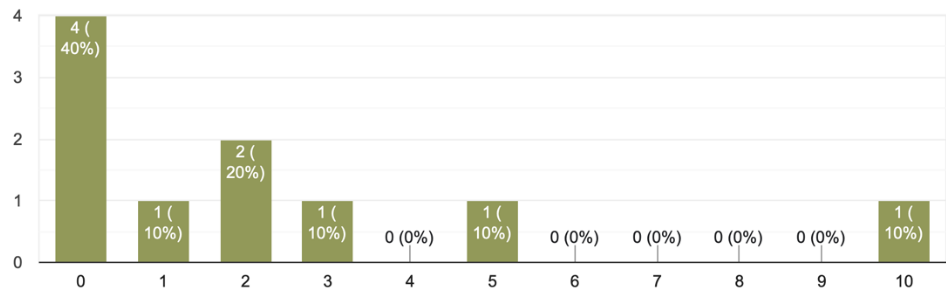


I had some more results to share, but this did not happen (for any reason)

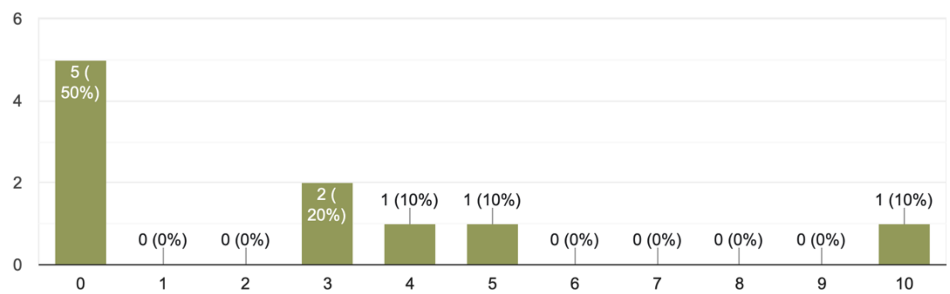
10 responses



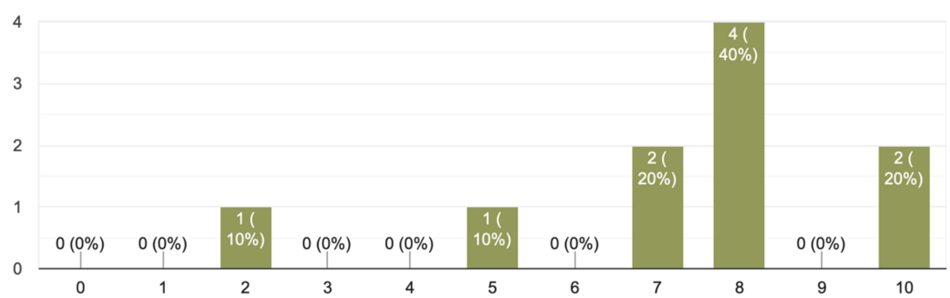
I wish we would not have spent time on this exercise.
10 responses



I wish we used the time for a classical teacher lecture on this topic instead.
10 responses

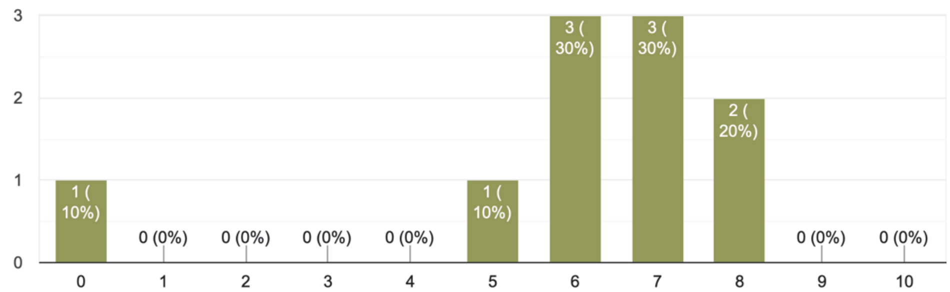


I felt more engaged in class by doing this exercise.
10 responses



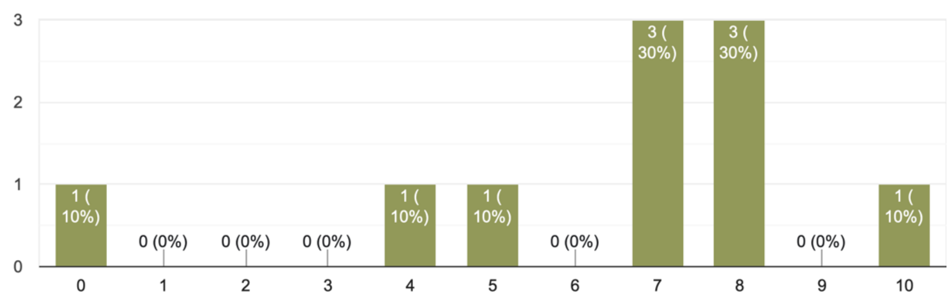
This exercise made me more interested in vegetation modelling.

10 responses



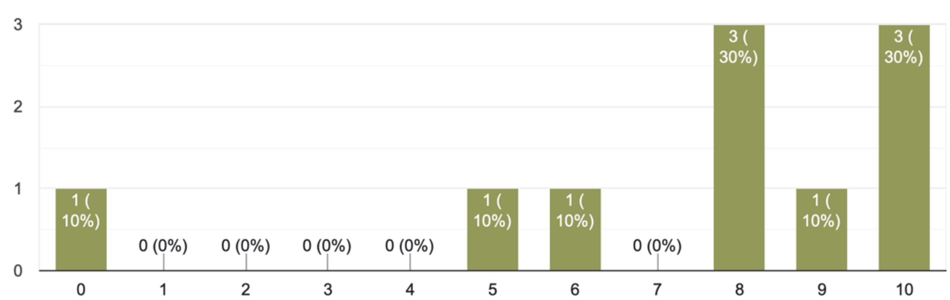
I learned something by the part in which I was discussing with my neighbors, and where we could draw our ideas on the template:

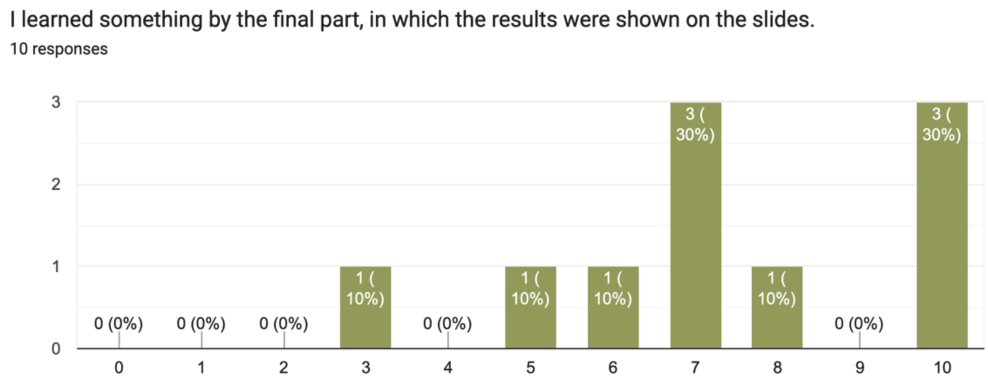
10 responses



I learned something by the part in which we all shared our ideas with the rest of the class, while the teacher drew everything on the blackboard.

10 responses




I learned something by the final part, in which the results were shown on the slides.
10 responses
3
2
1
0
0 (0%)
0 (0%)
0 (0%)
1 (10%)
0 (0%)
1 (10%)
1 (10%)
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7
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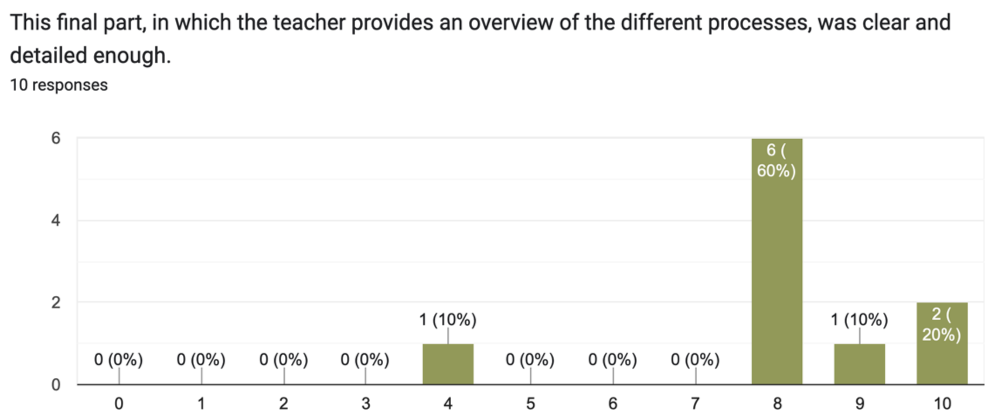
9
10


This final part, in which the teacher provides an overview of the different processes, was clear and detailed enough.
10 responses
6
4
2
0
0 (0%)
0 (0%)
0 (0%)
0 (0%)
1 (10%)
0 (0%)
0 (0%)
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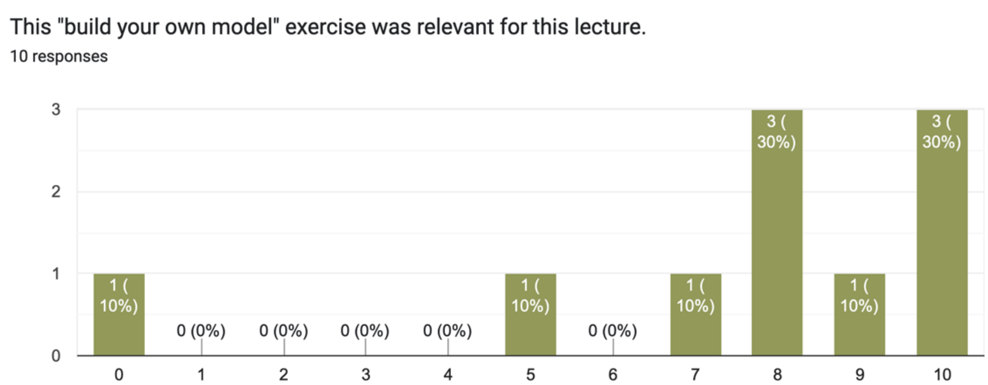
This "build your own model" exercise was relevant for this lecture.
10 responses
3
2
1
0
1 (10%)
0 (0%)
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3 (30%)
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This exercise helped to better understand what vegetation models are, how they work, and which processes are included.

10 responses