

HELPING TO MAKE SENSE OF REGIONAL CLIMATE MODELING

Professional Development for Scientists and Decision-Makers Anytime, Anywhere

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An increasing use of regional climate models has necessitated a new approach to professional development.

Many atmospheric scientists work within an institution where some level of teaching or professional development is required. Although a few professional development or capacity building courses exist, travel funding is not always readily available and many cannot benefit from the fast-paced advances in atmospheric sciences. Therefore, it is relevant to the community to have meaningful education practices that incorporate online learning as a way to make teaching and professional development initiatives more readily available. This paper

highlights a collaboration project, where atmospheric scientists, climate modelers, and science educators got together to develop two (independent) online courses on regional climate modeling. Our goal is to share the design and learning framework of each program and qualitatively compare them so that they can be considered as working models for other atmospheric science community members developing online courses about weather and climate models.

Climate science can play an important role in decision-making, but the problem is that there is a gap between decision-making and scientific processes, which turns course development into a nontrivial task (e.g., von Winterfeldt 2013). To address this gap at the global scale, the Intergovernmental Panel on Climate Change (IPCC) has been a driving tool to support governments with the necessary understanding of the climate science to make better-informed decisions. And as a global policy mechanism, the IPCC has been relatively successful in this function. However, decisions related to a changing climate are not just made on a global or national level but also on very local scales with significant consequences.

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For example, local governments and investors need to know whether the frequency of droughts in the next 50 years is expected to change in order to plan long-term infrastructure and water management. A lack of knowledge of potentially changing climate conditions, and in particular insufficient understanding of the uncertainties around global and regional climate projections, can lead to poor adaptation decisions. This is relevant to the atmospheric science community, because it is our responsibility to make this knowledge accessible. Therefore, utilizing effective learning strategies when teaching is imperative.

The past few decades have focused on the need to reduce emissions in order to mitigate climate change and prepare measures for adaptation. For instance, the Kyoto Protocol (UNFCCC 2014) and the subsequent Adaptation Fund (UNFCCC 2015) were the first steps to encourage the international community to reach these goals. This has led many developing world nations to feel some pressure to adapt to a changing climate, in spite of the fact that they may not have had the economic resources, proper infrastructure, or knowledge to accomplish that. In terms of knowledge, it requires understanding of high-level concepts of climate policy, climate science, and numerical modeling—and especially new model users suffer from what we call the “Warner effect”; that is, when model users are not properly trained, the value of the model simulations in the decision-making context are diminished (Warner 2011b). Examples of users of models and model data can range from researchers, teachers, environmental office employees, negotiators, and social scientists (though these groups did not necessarily participate in either courses presented in this paper).

Therefore, the emerging pressure to reduce emissions and adapt to a changing climate has created a vacuum between the need to achieve goals and the skills to accomplish them. In short, a robust training system is needed to support modelers and users of model data to develop their climate modeling skills. Then they will be able to effectively model and assess the impacts of climate change on their region and so be better informed as to what is needed to mitigate those impacts (Mesquita et al. 2011).

For the two courses discussed in this paper the users of models and model data were represented in the proportions seen in Table 1.

There are currently training courses regional planners can take, but these present a number of limitations (Mesquita et al. 2011): i) they are short-term courses, of about one week or so, and may not provide planners with enough practice and skills to implement changes in their countries; ii) these courses require participants to travel to another city or country, which becomes expensive if no funding is available; iii) these courses require prior knowledge that participants may not have, which limits the participation of some or isolates others from participating fully. Thus, while professional development courses can help support regional decision-makers in better understanding the climate science, access to such courses is often problematic through high costs, availability, and time constraints.

The aforementioned constraints may be minimized through the use of e-learning technologies, which provide an effective way to facilitate cost effective anytime, anywhere programs. These technologies are not straightforward to apply, as they require a solid pedagogical foundation for participants to benefit fully. For instance, many institutions have used e-learning tools, such as Blackboard or Moodle to provide their students with online resources. Unfortunately, some have used them as a repository of documents and handouts for students to download; that is, they do not take full advantage of e-learning pedagogical practices these programs provide. This highlights that whether the instructor wants to enhance his/her classroom with e-learning technologies or create a full online course, a solid framework needs to be in place. In this paper, we aim to provide a well-grounded framework, drawing on our experiences from two successful online courses we developed. Our hope is that professors, instructors, and educational/research institutions may use and adapt our framework to their current situation.

We also want to emphasize that not all teaching frameworks are effective in giving practical skills to learners. Some courses on regional climate modeling,

TABLE 1. Proportion of users of models and model data for the RECIPROCATE and m2lab.org courses.

Category	RECIPROCATE (%)	m2lab.org (%)
Students	18	65
Professors	28	13
Environmentalists	48	19
Social scientists	6	3

for example, have tended to focus on general principles rather than developing a technical understanding of how to apply them. Like all learning environments though, consideration needs to be given as to how the course is constructed and delivered. Too often with online courses, learning materials are placed on the Internet with little consideration of education theory and with the expectation that the decision-maker will be able to read, absorb, and apply this new understanding. However, a recent study (Walton 2012) shows that learners struggle to understand the relationship between concepts within a complex subject such as climate science, where the concepts are presented in different sources such as academic papers. This inability to link concepts reduces the learner's ability to develop a deep understanding of the science that is essential if successful decisions are to be made (Ackoff 1989; Atherton 2005). For example, if a learner reads a journal paper discussing the role of albedo in the energy budget and then reads another paper on deglaciation, they will not automatically link the relevance of changing surface type through loss of ice with changing the surface albedo. Therefore, all references to online learning in this paper refer to the development of a course that is grounded in education theory, rather than an online repository of content.

In addition, many participants who recently completed regional modeling courses still view climate and weather models as a metaphorical "black box," whereby data goes in and predictions come out. This limits the ability of users to go beyond running the model by mechanically repeating the process. As a result, they are unable to assess model limitations, determine whether their model simulation is reasonable, explore alternative scenarios in order to improve the simulation, and in general interpret the model output (Warner 2011b).

For participants to be able to develop a deep understanding of the climate science, specific criteria need to be met. First, the course needs to be presented in a range of ways that allows the individual to set the climate science into context for themselves, so they become central to the learning process rather than just a "passive" recipient of information (Vygotsky 1978; Yakimovicz and Murphy 1995; Fuller et al. 2000; Stefani et al. 2000). To achieve this, the social context becomes a critical part of the learning experience as an individual's ability to learn on their own is restricted until they are able to engage with someone with greater knowledge than their own (Vygotsky 1978). Within the two online courses we developed, this is facilitated both through direct engagement with the climate expert and also with the opportunity to engage in dialogue with other members of the course.

Dialogue within a coherent course structure allows participants to test their understanding with each other, which in turn helps them to construct their knowledge, building up understanding of the science (Dewey 1938; Kolb 1984). When we encourage the learner to reflect on how their learnt knowledge combines with new knowledge, they are better able to assimilate it into a broader understanding of the climate science (Dewey 1910; Popper 1979; Kuhn 1993; Driver et al. 1994, 2000; Duschl and Osborne 2002; Kinsella 2006). Within an e-learning course, discussion forums provide an excellent opportunity to facilitate this dialogue process and also allow the student time to reflect on the responses and consider their own understanding.

Utilizing the learning theories discussed above is a great way to create a course that will work for diverse backgrounds as well. All students come into a new course with varying levels of understanding of the material; therefore, the goal is to guide them along a learning progression so that they all end up further along than they started. Having the students share their ideas with each other is an excellent way to have students who understand the material better support the learning process of those who are further behind in the learning progression (Schwarz et al. 2009).

By comparing two independently developed courses we are able to see how these educational practices can be applied and, through an evaluation of the courses, understand what works, and as importantly, what does not. From this we can then consider what could be building blocks for a workable framework for other academics developing their online professional development courses on using and applying high-resolution regional climate models.

COMPARING TWO APPROACHES. It is clear that there is a need for regional planners to better understand climate science and in particular the appropriate use of regional climate model information in their work. It is also clear that while e-learning has the potential to facilitate professional development courses, to date the only online support tends to follow the style of a digital manual rather than a facilitated, educationally robust program (Met Office 2013; NCAR 2014). To better understand whether a more interactive online education as a platform for running professional development courses for regional decision-makers will indeed improve understanding, we compare two independently created online courses that introduce the science of climate change and how this can be applied in developing and interpreting regional climate models. Table 2 shows a summary of the differences between the two courses.

REGIONAL CLIMATE INTERNATIONAL: PROVIDING ONLINE CLIMATOLOGICAL APPLIED TRAINING AND EDUCATION (RECIPROCATE).

The first course titled Regional Climate International: Providing Online Climatological Applied Training and Education (RECIPROCATE) was developed in the United Kingdom as a collaboration between the University of Oxford and the Met Office using the Met Office's regional climate modeling framework Providing Regional Climates for Impacts Studies (PRECIS; Met Office 2011) as a practical example throughout the course. The course is an advanced module on regional climate modeling and climate science building on a free, nontutored, online foundation course that introduces the basic climate science and broader principles behind climate modeling. While the first course gives a very general introduction into climate science, the aim of the RECIPROCATE course is to equip participants with the necessary scientific understanding to use regional climate model output for concrete applied problems and design experiments themselves. The tutored course runs for seven weeks with each week being a distinct unit that builds on the learning from the previous week as seen in Table 3.

Learning materials provide the basic information, with the expectation that students would be supplementing knowledge through other sources such as journal papers. Key areas that are covered include uncertainty, regionalization, model validation, designing regional climate models, and climate scenario construction for impact assessments. Tutor support throughout the course guides the participants' thinking by giving feedback to questions or asking questions themselves to raise concepts and ideas not being addressed within the material and to spot and address misunderstanding of concepts and ideas. This equated to approximately 8 hours of tutor time a week. To provide this essential support by an active researcher fees apply to participate in the course; however, bursaries were available for

participants from developing countries. In addition, the course was initially designed to be part of the university's accreditation system; however, owing to administrative complications, this was only applied to the first run of the course.

To allow the students to test their understanding of the science, an asynchronous discussion forum was provided each week, which would be primed with key questions from the tutor to kick start discussions. Students were then given the time and space to post their own questions and respond to other students, with the tutor facilitating discussion rather than acting as a "font of knowledge." Typically students would spend approximately 12 hours per week reading the course materials, reading journal papers, and posting on the forums.

Figure 1 models the course structure and how reflection is used to help learners develop a deeper understanding of the climate science and its relationship to using regional climate models.

The course structure is built on a model developed by Walton and Carr (2011) that encourages learners to reflect on how different concepts presented each week relate to each other and how this developing understanding relates to the construction and application of regional climate models.

Each week represents a single "learning cycle" (Kolb 1984), where the learner is initially presented with some information in the form of course reading material (concrete experience). As the student works through the material, they have the facility to personally reflect on the text (reflective observation) and then to consider what the information means within their own context (abstract conceptualization) using the personal blog space. The students are then able to test their new understanding using the open discussion forums. This open forum allows a dialogue to develop between the students and the tutor, whereby understanding can be honed and directed in a way that might not be possible if the student were working

TABLE 2. Summary of the differences between the RECIPROCATE course and m2lab.org course.

RECIPROCATE course	m2lab.org course
Tuition fee to support tutor led	Free, tutor available for questions only
University accredited	Certificate of completion provided
Seven-week course	Eight tutorials, self-paced course
Links atmospheric processes to modeling content	Practical module to apply learning
High-quality scientific content	High-quality scientific content
Cyclical learning to promote reflection	Cyclical learning to promote reflection
Social and personal learning spaces	Social and personal learning spaces

TABLE 3. Course content and learning outcomes for the RECIPROCATÉ course.

Unit	Unit title	Learning outcome
0	Induction to online learning	Understand key principles of online learning and course expectations
1	Course introduction	Understand course structure and key concepts to be covered
		Summary of key scientific principles to be covered in the course
2	Uncertainties in the development of climate scenarios	Understand the term uncertainty in scientific context
		Understand how uncertainty applies in the different components of climate modeling
3	Regionalization techniques and regional climate modeling	Understand the role of spatial resolutions in climate modeling
		Understand how to downscale climate models
		Understand the advantages and disadvantages to the different downscaling methods
		Understand the role of regional climate models (RCMs)
4	Regional climate models	Understand the components of developing a regional climate model
5	Validating and evaluating a regional climate model	Understand how to assess a regional model in order to have evidence of how reliable the regional model is
6	Designing regional climate model experiments	Understand why a good experimental design is important
		Understand what factors need to be considered when designing an RCM experiment
7	Climate scenario construction for impact assessments	Understand how climate model outputs can be applied in impact assessments

in isolation. These discussions provide an opportunity to encourage the learner to consider how learning from one week relates to concepts identified in another and then to consider how this combined understanding can be applied to developing regional climate models. This is exemplified within the course, where in week 1 the students are given some text about the nature of uncertainty in science (concrete experience). They are then asked to consider what uncertainties they have identified in science (reflective observation) and next they have a chance to consider and record these thoughts in a way that is pertinent to their own situation (abstract conceptualization). The students are then asked to discuss this new understanding in the group discussion forum (active experimentation). This allows the student to actively test their new understanding of the concept before they move on to the next part of the course, which asks the student to apply their understanding of uncertainty within the context of climate science (new concrete experience).

M2LAB.ORG: REGIONAL CLIMATE MODELING USING WRF. The second course, m2lab.org: Regional Climate Modeling Using WRF, emerged from a framework developed by Mesquita et al. (2011)

and later created by Mesquita using his own resources to teach participants how to design, develop, and run high-resolution experiments with the Weather Research and Forecasting (WRF) Model (Skamarock et al. 2008). Today, m2lab.org runs and hosts other courses with the voluntary help of an educator, professors, and researchers. The courses are tutor involved, where the tutors develop course structure, materials, assignments, and most discussion questions ahead of time, but also make themselves available for participant questions as they come up. The course includes eight tutorials and is designed to take approximately eight weeks to complete. Like the RECIPROCATÉ course, it is primarily designed to support scientists and decision-makers in developing countries (Mesquita et al. 2011, 2013) by removing the need for expensive travel and access to supercomputing power. However, unlike RECIPROCATÉ, the course is self-paced rather than tutor led and therefore can be offered for free.

The m2lab.org course aims to help participants understand how limited-area models (LAM) work, learn about the climate system and how it relates to modeling, be able to set up an experiment design using the WRF Preprocessing System (WPS), run the

WRF model, and visualize model output and to interpret its results. A detailed list of tutorials is provided in Table 4. In each tutorial, students had questions and activities they could try on their own. Also, each course part had additional practical activities and a forum link, where questions could be posted. There were also extra reading assignments based on the book of Warner (2011a). The course does not require any prerequisites other than basic understanding of atmospheric science. It is up to each participant to decide whether they are ready for the course; however, since the course is self-paced and free, if the participant decides to put the course on hold or decides not to finish it, they can do that with no consequence.

The fundamental difference between the two courses is that the m2lab.org (Mesquita 2014) requires the participant to actively engage with the modeling software and directly run the model rather than just discussing the theoretical and practical applications. The participants are able to use a virtualized version of WRF (e-WRF; Mesquita 2013) and other necessary software on to a virtual hard disk, allowing the model to be run on the participants' personal computers, regardless of their operating system with no need for the use of a supercomputer.

In a similar fashion to RECIPROCATE, m2lab.org is divided into eight units, called tutorials, each of which is designed to guide the user simultaneously through the development of content related to regional climate modeling as well as the developing of a research question to explore using model simulations. Similarly, the m2lab.org course encourages the participants to reflect on their understanding as they progress through the units resulting in a cyclical learning process similar to RECIPROCATE.

However, as the participants have to complete a practical element of the course, the cyclical structure of the m2lab differs from RECIPROCATE as can be seen in Fig. 2.

As with the RECIPROCATE course, participants are initially given information about climate science and how it relates to regional climate modeling, along with an activity to guide their understanding. The participants are encouraged to refer to Warner (2011a) as a key text for understanding the climate science. Discussion forums provide a space for social reflection where participants can test their understanding of the science and have a chance to receive feedback from other participants or the course tutor on ways to develop their thinking of how to design and develop regional climate models. Generally, peers support each other by providing feedback to those posting about tutorials they have already completed. This process can be repeated within the tutorial, as many times as the participant wants, until they feel confident with the material.

While reflecting on the new information, the second part of the tutorial asks them to apply the information to a situation of their interest. The process is represented in the box on the right side of Fig. 2. Participants are encouraged to think of a research question that they could answer with data obtained by running WRF. They are also asked to set up the model so that they can gather data in order to answer the research question that they asked themselves. As each tutorial is completed, new information is presented that can (and frequently does) cause the participant to reevaluate the research question they want to ask, the experiment design they are generating, and the data they want to gather. Therefore, this process

cycles through at least once for each tutorial.

Having completed all the units, participants run the model and then use the data generated to derive evidence in order to make a claim that answers the question they wanted to originally test. The results from the evidence-gathering and claim-making processes are reported to the instructor as a written reflection piece, which is the final assignment to complete the course. In doing this final step, students are applying their content knowledge of

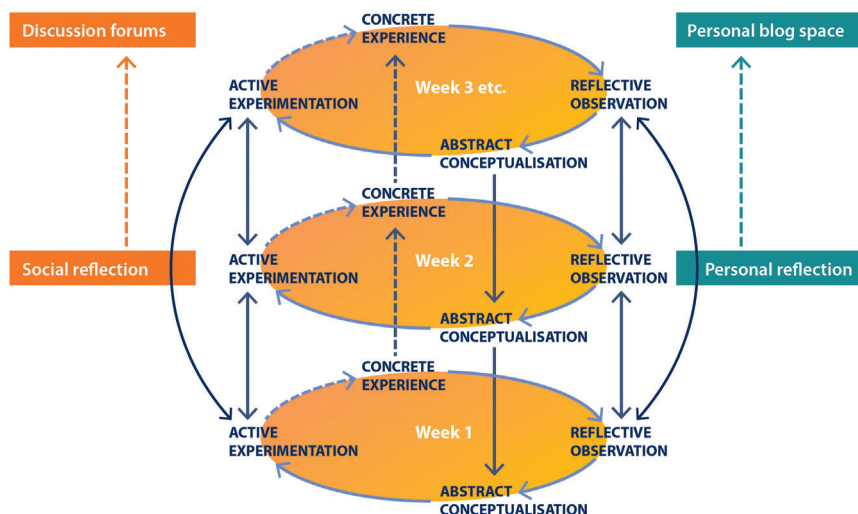


FIG. 1. RECIPROCATE course structure.

TABLE 4. Course content and learning outcomes for the m2lab course.

Part	Content	Learning outcomes
0	Tutorial 1: Course introduction, preparation, and forum instructions	Understand the course structure
	Forum discussion	Introduce oneself to other participants
1	Tutorial 2: e-WRF installation and learning how to work with Ubuntu Linux (Ubuntu 2013)	Set up e-WRF
	Extra reading assignment: Warner (2011a), chapter 1, 1–5; chapter 16, 432–453	Learn how to use Linux
		Make a plot using ncview (Pierce 2013)
2	Tutorial 3: WRF experiment design, reflective learning	Set up an experiment design
	Extra reading assignment: Warner (2011a), chapter 3, 25–42	Establish a scientific question and design an experiment to answer it
	Self-assessment: Reflective learning	Make a decision on which resolution could be used
	Forum discussion	Choose a proper domain size
		Select an appropriate projection
3	Tutorial 4: WRF Preprocessing System (WPS)	Understand the role of the WPS system
	Extra reading assignment: Warner (2011a), chapter 3, 96–117	Learn how to edit and change a namelist.wps file according to the experiment design needs
		Plot the domain information using the NCAR Command Language (NCL) software (NCAR 2013)
		Study how to create nested domains in WPS
4	Tutorial 5: Lateral boundary condition (LBC), ungrib.exe, and metgrid.exe	Learn how to download LBC data for producing a weather forecasting or a climate simulation
	Extra reading assignment: Warner (2011a), chapter 4, 119–140	Learn how to convert the LBC data to the WRF Intermediate Format using ungrib.exe
		Learn how to interpolate these data to your own experiment design setup using metgrid.exe
5	Tutorial 6: Running WRF, real.exe, wrf.exe	Understand and edit a namelist.input file
	Extra reading assignment: Warner (2011a), chapter 4, 140–155	Determine the time step needed for an experiment design
		Run real.exe
	Assessment: Computer marked assessment	Run wrf.exe
		Visualize the outputs from real.exe and wrf.exe
6	Tutorial 7: WRF for climate simulations, parameterization schemes	Learn how to plot wrfout files using NCL
	Extra reading assignment: Warner (2011a), chapter 4, 155–168	Understand the concept of parameterization schemes
		Practice how to change parameterization schemes in WRF
		Study how to extract time series data from WRF using a tslist
		Learn how to use SST update in WRF

TABLE 4. Continued.

Part	Content	Learning outcomes
7	Tutorial 8: WRF for climate simulations part II, tropical channel domain, applications	Learn how to couple WRF to a simple mixed-layer ocean model
	Extra reading assignment: Warner (2011a), chapter 5, 171–196	Set up a tropical channel simulation
	Self-assessment: Final reflective learning	Understand how the “lat–lon” projection can be used for a CORDEX domain
	Tutor-marked assessment: End of course assignment	Practice the use of WRF applied to a case study: the NARGIS cyclone
		Learn best practices and apply them to climate research

the atmosphere as well as their technological knowledge of the model in order to reinforce their understanding of the content, technology, and how they work together to create the results that they get from their model run.

DEVELOPING A FRAMEWORK. The two courses represent two possible models of delivering professional development on understanding and applying high-resolution regional climate models with many similarities but also some significant differences. Both courses have their individual strengths and weaknesses; in fact, the strengths of one course are often weaknesses of the other. By comparing and contrasting the two modes of delivery and reflecting on the course evaluations completed by tutors and students, it will be possible to evaluate their efficacy

for both the participant and the organization delivering the course.

In terms of participants, the online platform allowed both courses to recruit professionals from economic developed and developing countries, though both found that the majority did come from economic developed countries. The global distribution of participants from both courses is illustrated in Fig. 3 with those attending the m2lab.org course in red with the RECIPROCATe participants in green.

Both online courses provide the quality of content and structure that Mesquita et al. (2011) suggest is missing from previous courses. Running the course for a minimum of seven weeks (or possibly longer for some participants in the m2lab.org course) allows the participants to engage with more of the scientific content that informs regional climate modeling providing them with a better understanding.

The length of both courses also allows the participants to revisit the science in a range of contexts giving them the opportunity to deepen their knowledge by making the connections between the different concepts as suggested by Ackoff (1989) and Atherton (2005). Mesquita et al. (2011) also suggest that current professional development courses, particularly for those in economically developing countries, necessitate travel that incurs costs and thus dramatically limits the accessibility. The online environment used

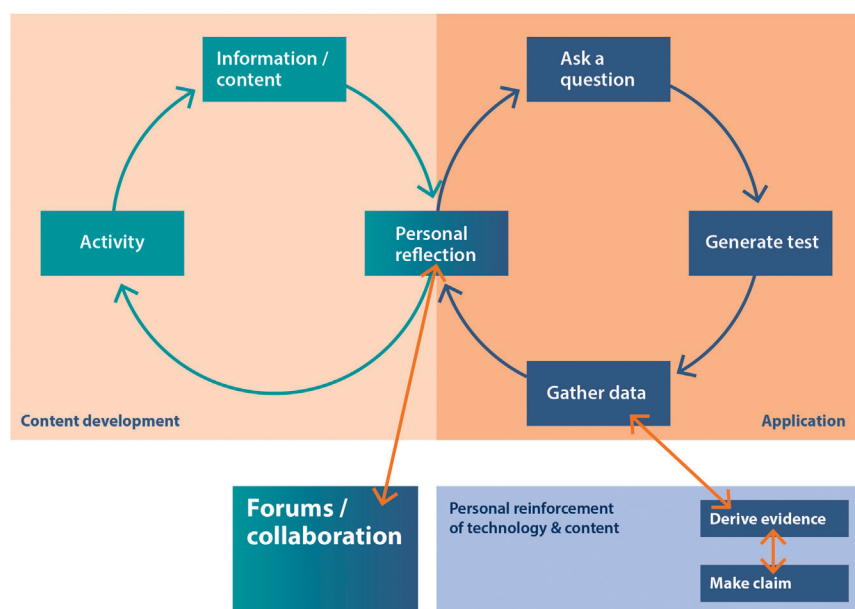


FIG. 2. Model framework for the m2lab.org online course.

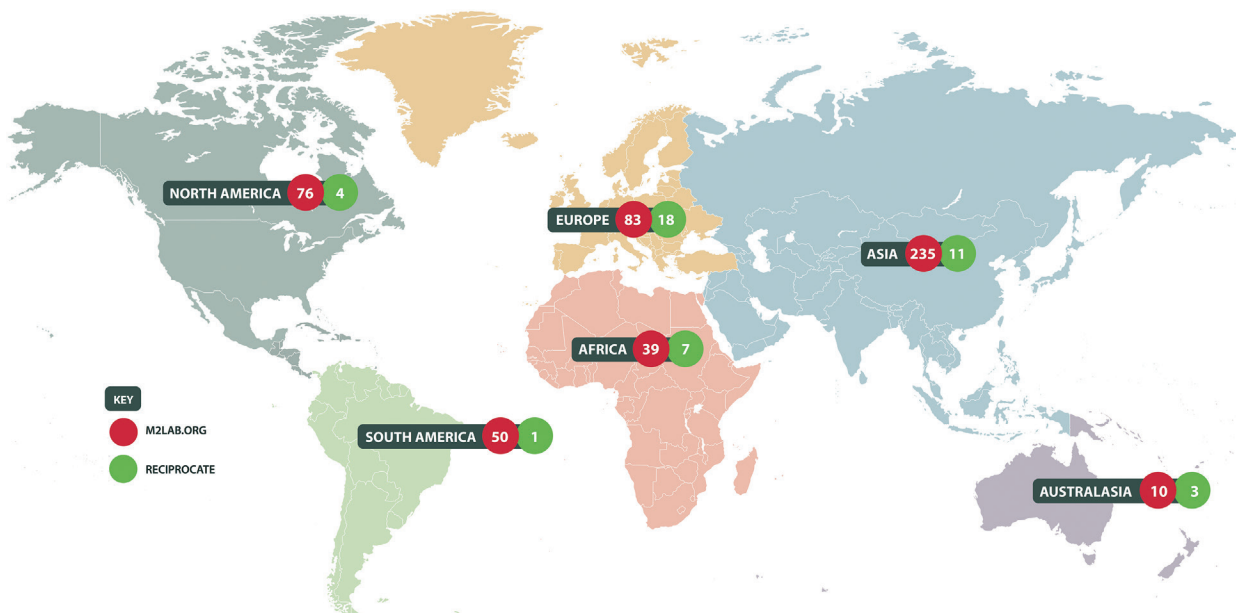


FIG. 3. Global distribution of participants on the m2lab.org and RECIPROCATE courses.

by RECIPROCATE and m2lab.org does remove the need to travel for the educational program; however, it does require a good, reliable Internet connection that is not always available in economically developing countries. Both courses have minimized the need for a fast broadband connection by keeping the learning content simple, using text and graphic-based content, rather than hypermedia (video and audio). In addition, m2lab.org allows the participants to run the computer models offline, reducing the need to have fast Internet connection. Participant feedback from both courses suggests that, in fact, participants would like to see more hypermedia used, though this would not only have an impact on access but also on resource development costs.

While the online environment can be seen as an efficient delivery mechanism, problems with participant retention exist (Rovai 2003) as experienced by the m2lab.org course. It was seen by the tutors that participants were often “strategically” dropping out of the course, for example, getting as far as understanding how to run the model but then leaving straight afterward. Also, participants would register for the course as a way to access information that they could then use for their own teaching and so appear as noncompletion on the course statistics. This was not the case with the RECIPROCATE course, where all students who had registered completed the course although with very little active contribution in some cases. The reasons for this have not been explored, though it could be because the RECIPROCATE

course is a defined time rather than open ended, like the m2lab.org course, or that the tutor was able to communicate directly with the participants on a regular basis, allowing them to address the participants’ welfare as well as problems with the course material. This direct involvement of the tutor on the RECIPROCATE course though does come at a cost in terms of paying for the tutor’s time to instruct. To make the course sustainable this cost was passed on to the participant with the idea being that there would be a tiered fee structure with the added support of bursaries. This model was designed to ensure that the course fee did not act as a barrier to participants though in practice it could have resulted in a lower attendance on the course. This could be viewed in contrast with the m2lab.org course where there was no fee and an attendance level at time of writing of over 500 people compared to the approximately 100 people over the four runs of the RECIPROCATE course. In addition, though, by not charging participants a course fee it is not possible to pay tutors’ time unless additional funding is obtained, relying on the good will of the tutor.

Educationally, both courses draw on the good “classroom” practice that is seen in the literature. The broad nature of the content in conjunction with tutor questions allows the participants in both courses to consider the science in the context of their own situation as suggested by Vygotsky (1978). Vygotsky (1978) also suggests that it is important to allow the learner to engage with other people who have greater

knowledge than themselves in a discipline, which both courses do through the use of tutors and by providing opportunities to talk to the other participants in the discussion forums. As suggested by Dewey (1938) and Popper (1979), opportunities to reflect in social and personal spaces on the science and how it can be applied are provided by both courses through online discussion forums and assessments. Interestingly, both courses found that participants would often use the forums strategically (e.g., to get an answer to a specific question) or would often “lurk” through reading the posts but not respond to them. The RECIPROCATe course tried several measures to encourage students to be more active, though no one measure seemed to be successful on all occasions; therefore, a range of measures were used over the period the course was run.

The fundamental difference between the two courses is the extent to which the participant actively engages with a regional climate model. While the RECIPROCATe course encourages participants to reflect on the science and how it can be applied when running the PRECIS model, there is no point when they are asked to run a model they have developed. Indeed, they could theoretically complete the course without touching the model. By focusing on the academic principles of regional climate modeling, it provides the participants with an excellent foundation of the theory and practice of experimental design but does not give them the technical experience. It also meant that the course could be more accessible to a larger number of people as they did not need any specific programming or mathematical skills and thus explicitly addressed those aiming at using and interpreting model output without involvement in the simulations. This also had the effect whereby some participants felt there was not enough mathematical content. The lack of practical experience on the course could be easily addressed by adding two more units. These could focus explicitly on implementing the experiment that students have to design in their final assignment. This would have the advantage of leading to the creation of a suite of modules that could be taken together similar to a degree program or, taken individually, depending on what the participant wants to focus on. The participant feedback for the RECIPROCATe course does refer to wanting more hands-on exercises with using the PRECIS model.

In contrast, the m2lab.org course does offer participants experience of applying their theoretical knowledge of the climate science in designing and developing experiments using WRF. Not only does this help reinforce the science but also helps to remove the

perception of regional climate models being a black box. Being able to run an educational version of the WRF model on their own computers does facilitate a wide engagement of participants from economically developing countries who may not have access to large supercomputers; however, having enough bandwidth to be able to download can be problematic to some participants. This course structure though does reflect more closely Kolb’s (1984) model of experiential learning, where it is suggested that participants will form deeper understanding concepts (in this case climate modeling) through actively participating in an exercise.

The final point to be taken from comparing the two courses is the issue of certification. As well as wanting to develop their own knowledge, participants also indicated that they took the course as part of their professional development and, as such, required some form of certification. To reduce costs, the m2lab.org is not accredited to a university and so cannot offer university credits that participants could use toward a degree. Instead, they are able to award a certificate of completion. In contrast, the RECIPROCATe course was developed to provide participants with accreditation that was seen as a positive for the initial cohort taking the course. However, the administrative procedures in having the course accredited proved problematic and subsequent runs of the course were offered with only a certificate of completion. From the student course evaluation, this was not seen as a negative aspect, as the students did not see this course as leading to a degree, but having recognition that they had completed a course from the University of Oxford was the most significant factor.

From the discussion it is possible to identify a series of key areas that are important to consider when developing a professional development course on regional climate modeling. Each course has its own strengths and weaknesses, but the strengths support the goal of the course. For example, the m2lab course cannot be used for continuing education credits because it is not associated with a university; however, because it is not part of university curriculum, it can be offered to participants for free. Key areas to consider when developing a professional development course on regional climate modeling include the following:

- 1) Content:

Both courses were designed in collaboration with leading atmospheric scientists and as such reflect the key concepts and ideas fundamental to understanding high-resolution regional cli-

mate modeling. However, because of the broad nature of the discipline, consideration needs to be given as to what content is covered and how it is covered. Some participants will want a more math and physics focus while others may want a more applied approach. It is important in every case though to refer to recent publications and development so participants immediately see that they are educated on the forefront of scientific development.

2) Structure:

A short course broken down into discrete units helps guide the participants' understanding and allows them to structure their learning in an organized way. A cyclical program encourages reflection on the different concepts and lets the participants apply this learning in a range of ways that is relevant to their context.

3) Pedagogy:

It is important to ensure that the course uses a sound educational approach that places the participant at the center of the learning experience and gives them opportunities to reflect and test their thinking in new contexts relevant to them. Recognizing the relative strengths and weaknesses of an online environment as identified in the literature and evaluated in the previous section of this paper is critical.

4) Cost:

E-learning can provide a cost effective delivery mechanism for professional development courses on regional climate modeling, though consideration needs to be made with regards to how much of any cost is passed on to the participant. Too much and you limit the potential market, while too little provides a greater strain on the provider and may limit what the course can offer in terms of content and tutor time. Bursaries and funding structures can support lower income participants but these can be problematic to administer.

5) Theory versus practice:

Many educational theorists suggest that deeper learning can be achieved through practical activities as a way of reinforcing understanding; however, depending on the aims of the course, this may not be necessary. It may be enough that participants have a good theoretical understanding of the science and how it can be applied to their own contexts, but if they are to become

skilled in using the modeling software, having an opportunity to use it with the support of an expert is critical.

6) Accessibility:

Online learning can provide access to high-quality professional development courses; however, consideration needs to be given to the quality of Internet access that participants may have, and this could impact on their ability to access course materials or appropriate software to run the models.

7) Certification:

Learning for learning's sake is the motivating factor for only a few participants; therefore, being able to offer them evidence of attendance on a course as part of their professional development program can be important. Levels of recognition exist from certificate of attendance/completion to full accreditation points. However, participants may view the value of a course differently depending on the level of achievement. Issues in relation to institutional administration and stringent assessment can be limiting factors to offering full accreditation.

8) Community:

Being able to learn from your peers is a key aspect of educational processes regardless of the environment, and so the extent to which a community of learners is created is important in an online environment. Participants need to be encouraged to engage with the discussions, though often this can be problematic where no single solution is available.

CREATING A COMMUNITY. While regional climate models can play an important role in helping atmospheric scientists understand the impacts of climate change, unless people have adequate training on how to use them and apply the results, there will always be the potential for poor decision-making and potentially costly mistakes to be made. Access to quality professional development courses can be problematic, but this paper shows that online learning can begin to close the gap between decision-makers and the scientific process if a framework is developed that facilitates the learning process effectively.

This paper discussed two independently designed, online regional climate modeling courses that utilize educationally robust strategies to develop similar, but distinctly different, professional development frameworks that can exploit the time and cost efficiencies

associated with e-learning. However, consideration needs to be given to course design that recognizes the requirements of the participant, the resources available to the developer, and the aim of the program. Providing a practical focus to the course provides an opportunity for participants to test their knowledge and apply it to a context relevant to them, but this needs to be balanced with the time it takes to complete the course, accessing the software to run the models and tutor time needed to answer practical questions. Simply providing some decision-makers with a better understanding of the science of regional modeling and what are suitable applications of the technology may be enough to support their work without the need to understand how to run a model in practice.

It has been seen that it is not possible to design a “perfect course,” but we hope that this paper demonstrates what we consider to be essential: good educational principles. Model users and users of model data require a range of courses to suit their needs in terms of the science that is covered, the time it takes to complete, the cost, level of professional recognition, and the style of the educational experience. Academics also need to consider that they will be able to provide different expertise with regards to the science and how models can be applied in different contexts. By building on the strengths of the academics and their institutions and meeting the diversity of stakeholder needs, ultimately we will develop a greater range of courses and users that will strengthen the modeling community. The challenge will be in communicating with the existing regional modeling community to identify where the possibilities lie and how best to support the decision-makers they work with in using and applying regional models.

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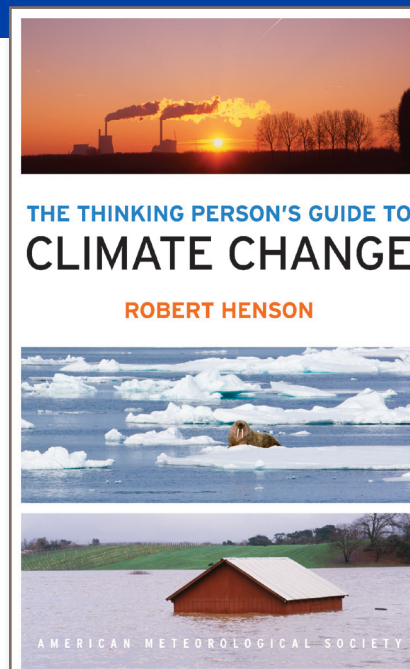
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