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PERSPECTIVE

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Promoting interdisciplinarity through climate change education

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Climate change is a complex scientific and social problem. Effectively dealing with it presents an immense challenge, yet educating students about it offers educators in science, technology, engineering and mathematics (STEM) fruitful opportunities for promoting interdisciplinarity, retaining talented young people in STEM fields and enhancing multiple literacies of all students. We offer three illustrative examples of interdisciplinary climate change-related STEM education projects. Each of these models is designed deliberately for implementation in the first two years of collegiate-level STEM courses; thus, they may be employed in both four- and two-year institutions. The scientific community can use climate change education opportunities to help further transform STEM education in the US and increase production of high-quality STEM graduates.

Climate change is arguably one of the most serious challenges we face, made all the more difficult to address by its interdisciplinary nature. Despite advances in the science of climate change[1], both knowledge and understanding of climate change in the US are weak at best in the general public[2–4], among college students in general[5] and even those students in the STEM disciplines[6]. This has much to do with the fact that the science of climate change is exceedingly difficult for educators to teach and for students and audiences of all ages to learn[7,8]. However, we believe that teaching climate change to students represents a golden opportunity not only to improve their knowledge and understanding of the diverse array of issues encompassed by climate change, but also to promote interdisciplinary process skills that are paramount to solving twenty-first-century problems.

Many appeals for improving the quality of STEM education argue that undergraduate courses should provide students with experience in applying scientific principles to major real-world problems in an interdisciplinary context[9–11]. Moreover, to enhance students' quantitative literacy (which includes, among other things, the abilities to perform basic computational operations, solve quantitative problems across a wide range of contexts and situations and create and communicate arguments supported by quantitative evidence), experts recommend integrating mathematical and statistical concepts across the STEM curriculum[12]. This has led STEM educators to implement inquiry-based projects that allow students to use data, modelling or mathematical formulae to understand important concepts in different STEM disciplines[13].

The very characteristics that make the science of climate change challenging — interdisciplinarity, the complex integration of observational data, laboratory results, computer modelling and so on — offer STEM educators key opportunities for enhancing students' scientific and quantitative literacies as well as plugging leaks in the STEM pipeline. Furthermore, overcoming cognitive barriers to understanding climate change may demand certain curricular and pedagogical shifts. In this Perspective, we discuss some ideas about how scientists can use climate change education to promote interdisciplinarity, keep talented young people in STEM fields and help all students to enhance their scientific[14,15], quantitative[12] and climate[16] literacies.

STEM education and multiple literacies

Amidst mounting pressure to provide evidence of the value added by a broad liberal arts curriculum[17,18], universities have been cultivating interdisciplinary teaching and learning[19] and promoting a shift from a focus on teaching (that is, what instructors do) to focusing on learning (what students do)[20]. At the same time, STEM education scholars find that learning activities that are hands-on, collaborative and oriented to real-world problem-solving may be effective in keeping young people in the STEM pipeline[21,22]. Even more generally, working on authentic, ill-structured problems — such as climate change — is essential for promoting students' intellectual development[23,24].

STEM education researchers have improved our understanding of which teaching and learning contexts, strategies and techniques facilitate STEM learning at the university level[25,26], and climate change education is a useful venue to implement these insights and 'best practices'. At the same time, scholars may use climate change education as a promising avenue through which to advance STEM education research. The issue of climate change allows STEM educators to teach students how general scientific principles and processes across interconnected disciplines are employed to address a real-world problem that has wide-ranging societal implications.

Despite a reticence in STEM faculty to change their teaching styles[27,28], a greater understanding of how individuals learn[29,30] has led to a slow adoption of more student-centred teaching pedagogies at the university level[31–33]. Active learning approaches to teaching have consistently been shown to increase student learning[32,34] and favourable attitudes of students[35,36] and teachers[37] towards the subject material. As a result of this growing body of evidence, the Association of American Universities launched an Undergraduate STEM Education Initiative in 2011 to move from research to implementation of these best practices in introductory undergraduate science courses[38].

One method of active learning that lends itself well to climate change education is problem-based learning (PBL), which requires students to focus on problem analysis, knowledge application and cooperative work around relevant issues[29,39]. Comprehensive examples of this exist for teaching general concepts and principles in chemistry[40], biology[41], physics[42] and mathematics[43]. Several

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studies find that PBL approaches to teaching have a positive effect on students' retention and synthesis of knowledge and/or interest in the subject[44–48].

To implement active learning approaches such as PBL, there is an emerging body of climate change education resources that may be used across a university curriculum. The National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF) are funding interdisciplinary research on climate change education through the Innovations in Climate Education Program[49] and Climate Change Education Partnership Program[50], respectively, whereas the National Oceanic and Atmospheric Administration's Communications and Education Program in its Climate Program Office[51] is facilitating the dissemination of such climate change education resources. In social sciences and humanities courses that address climate change, instructors may supplement their course content with these resources to help students learn climate science essentials crucial for increasing learning gains from course readings, discussions and activities. STEM instructors can also integrate resources easily into disciplinary and interdisciplinary courses, allowing them to achieve the equivalent coverage of core concepts through an emphasis on climate principles.

To effectively use these climate change education resources, STEM instructors should be aware of the type of barrier or inappropriate mental model that is keeping students from understanding climate change. Although identification of these cognitive barriers to climate literacy should itself be the focus of a sustained research agenda, we speculate here on likely obstacles, as they are probably the same as those that hamper understanding of complex issues more generally. The key assumption is that, unlike complex, nonlinear and dynamic climate phenomena, most students' mental models are simple, linear and static. Active engagement in the topic of climate change — especially with regionally relevant data — may force students to abandon inappropriate mental models and adopt a more dynamic approach. Which pedagogies and strategies are more or less effective in promoting this shift to systems thinking — and the learning of nonlinearity, stochasticity, feedback loops and so on — should be the focus of sustained STEM education research. An important strategy is addressing students' knowledge before beginning a course or unit. This will help to identify inappropriate mental models and factors that may promote motivated reasoning[52].

Much has been written about the need to increase production of high-quality STEM graduates[26,53] and about the leaky STEM pipeline in the US, especially for women and racial minorities[54]. Because climate change is a real-world problem with wide-ranging impacts — intelligible only with the integration of understanding across multiple disciplines — an intentional, sustained focus on climate change in a STEM curriculum may help to reduce the loss of graduates from these disciplines. Female and minority students often find STEM courses more relevant and interesting when they engage in hands-on activities dealing with real-world problems or applications[21,55]. Using the best practices in the STEM education literature, STEM instructors can create different collaborative learning and inquiry-based learning activities[27,56]; for example, asking students to work in teams to test hypotheses of their own creation with regionally relevant climate data.

Perhaps even more important is the science education of non-STEM majors, who also will need to make informed decisions about climate change as citizen stakeholders. This means that we must enhance multiple literacies of all students. STEM instructors can refine the learning objectives of their courses for non-majors to align them with the key recommendations in the reports on these literacy standards.

Three potential interdisciplinary STEM education models

Given the torrent of research funding for climate change education research in recent years, many modules and techniques are now being produced and disseminated[49–51]. As part of an iterative design process, STEM education scholars should systematically examine the effectiveness of these products for increasing student learning gains. Core ideas from biology, chemistry, physics and mathematics — and arguably from the social sciences — are all necessary to fully understand important climate literacy principles[16]. Yet, in many undergraduate STEM curricula, climate change education at best consists of a few disconnected lectures in different courses. As such, the concepts are rarely reinforced and unlikely to be connected in an interdisciplinary fashion. Students emerge from this pot-pourri education unable to understand the complexities of climate change or to apply this knowledge to problem-solving[5,6]. Thus, we do need our climate change-related STEM education to be at least partially interdisciplinary.

For the purpose of illustration, we briefly discuss three examples of interdisciplinary climate change-related STEM education projects. Each of these models is designed specifically for implementation in the first two years of collegiate-level STEM courses; thus, they may be employed at both four- and two-year institutions. The first model is a short-term project that can be implemented in a single general science course, and the other two projects span an entire STEM curriculum — one lasting a week and the other lasting a year.

Hockey stick project. Although the data embodied in the famous 'hockey stick graph'[57] is not the sole evidence of recent climate change, it is emblematic of the scientific efforts relating to it, and a focal point for climate change scepticism[58,59]. Exploration of the biophysical and social science aspects of the hockey stick graph may provide students with an interdisciplinary, inquiry-based experience.

After briefly explaining the details and meaning of the graph, the instructor would divide up the class into groups of five students each. Each student in a given group would be assigned to research and teach his/her classmates one of the following topics related to the hockey stick graph: (1) the creation and emission of greenhouse gases such as carbon dioxide (biology, chemistry); (2) the means by which greenhouse gases trap heat in the atmosphere (physics); (3) the methods that are used to determine the points on the hockey stick graph and their possible limitations (biology, chemistry, physics); (4) the reliability of the graph in terms of its diverse data sources (statistics); and (5) attacks on this graph by climate change sceptics, including the 'Climategate' scandal in late 2009[60] (history, sociology). In subsequent class meetings, students from different groups that were assigned to research the same topic would collaborate to refine their understanding of their respective topic. Those students would then return to their original group to present their findings, and other members of their original group would do the same. This process would ensure that all students in each group have been introduced to all of the key issues associated with the hockey stick graph. Following this group-level peer learning, the instructor would facilitate discussion on unclear or controversial ideas before summarizing the main points. This project may also be used to segue into a more extensive assignment, such as reading and discussing Michael Mann's recent book on the hockey stick graph[61].

Climate change week. As noted earlier, STEM educators will soon begin using the climate change education modules and activities that are being produced by NASA- and NSF-funded research. How might the effectiveness of these resources be enhanced by embedding them within a structured short-term interdisciplinary programme? First- and second-year college students are often enrolled in some combination of chemistry, biology, physics and mathematics/statistics courses, creating a setting where students could simultaneously be exposed to different approaches to understanding climate change and its impacts. This might allow for the creation of a 'Climate change week' programme that intentionally integrates courses across the STEM disciplines for a week of intense focus on climate change in the university's geographic region.

During this time students would be encouraged, perhaps by offering extra credit, to sit in on other courses to learn about the relevance of other disciplines to understanding climate change. At institutions where cross-disciplinary collaboration is strong, STEM instructors would co-teach each other's courses; for example, a chemist would teach fundamental climate chemistry in a biology course, and a biologist would introduce the biological impacts of climate change in a statistics course. Also, extracurricular events — such as invited lectures, interactive workshops and student poster sessions — would further promote interdisciplinary learning on climate change. This short-term programme may facilitate cross-pollination across the STEM disciplines so that students have a more complete understanding of climate change in their region. Given its short duration and low logistical demands, this may be easily implemented at many colleges and universities across the US. Even greater learning gains might be achieved through a long-term interdisciplinary programme.

Climate change semester or year. A long-term course may involve a team-taught seminar series in which students who are also co-enrolled in several STEM courses would actively discuss and perform inquiry-based learning projects with climate change data from their region. Coordination with the instructors of the other STEM courses would be essential to facilitate the integration of their course content into the seminar. This long-term programme would allow for a more in-depth climate change curriculum to be simultaneously taught across a range of STEM disciplines to co-enrolled students. In addition, if the instructional team included a social scientist, the programme could address how humans have responded to climate change (both cognitively and behaviourally), educating the students not just in the biophysical sciences, but also in the social sciences. It may be challenging to implement this course at many US institutions due to the duration and resources required. Yet, it is likely to translate into significant learning gains — and be a springboard for students considering graduate studies in climate-related fields.

We recommend that instructors wishing to implement one or more of the above programmes begin by assembling an interdisciplinary team committed to improving climate change education. Ideally this group would include both biophysical and social scientists, although we have focused mostly on biophysical science here. The team would then decide how to proceed at its institution, modifying the models as necessary and perhaps conducting STEM education research on the effectiveness of different strategies and pedagogies for increasing students' scientific, quantitative and climate literacies.

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