The Journal of Economic Education

ISSN: 0022-0485 (Print) 2152-4068 (Online) Journal homepage: https://www.tandfonline.com/loi/vece20

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To cite this article: Lea Fortmann, Justin Beaudoin, Isha Rajbhandari, Aedin Wright, Steven Neshyba & Penny Rowe (2020) Teaching modules for estimating climate change impacts in economics courses using computational guided inquiry, The Journal of Economic Education, 51:2, 143-158, DOI: 10.1080/00220485.2020.1731383

To link to this article: https://doi.org/10.1080/00220485.2020.1731383

Published online: 26 Feb 2020.

THE JOURNAL OF ECONOMIC EDUCATION
2020, VOL. 51, NO. 2, 143–158
https://doi.org/10.1080/00220485.2020.1731383

ECONOMIC INSTRUCTION

Teaching modules for estimating climate change impacts in economics courses using computational guided inquiry

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ABSTRACT
The authors of this article introduce two teaching modules that aim to increase climate literacy and active learning in undergraduate economics courses through the incorporation of real-world data and modeling. These modules are based on the concept of computational guided inquiry (CGI), which combines a guided inquiry approach within a computational framework, such as Excel. In one module, students estimate and graph expected marginal damages due to regional sea level rise for various polar ice melt scenarios. In the second module, students partially replicate a journal article estimating the total economic value of ecosystem services in the Arctic. These modules have been used in urban, environmental, and climate change economics courses, and are ready to be implemented with minimal upfront cost to instructors.

KEYWORDS
active learning; climate change; economic modeling; environmental economics; guided inquiry; Microsoft Excel; real-world data; urban and regional economics

JEL CODE
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There has been a growing recognition in the field of economic education that the theoretical models that make up the majority of the content in economic principles courses do not readily align with real-world applications and do not do a sufficient job at promoting economic literacy (Hansen, Salemi, and Siegfried 2002; Ormerod 2003; Becker 2004; Salemi 2005). Furthermore, studies have found that students who have taken economics courses retain very little of the knowledge gained during the course and often have a poor understanding of basic economic concepts (Walstad and Allgood 1999; Hansen, Salemi, and Siegfried 2002). To address these issues, Hansen, Salemi, and Siegfried (2002) recommend that courses move away from traditional lecture-based formats to allow for more active-learning opportunities in the classroom, along with an increased focus on real-world issues and problems and how they can be explained by basic economic principles. Active-learning strategies, such as group projects or cooperative learning, have also been found to improve student retention of material (Kvam 2000). We introduce a series of computational teaching modules that incorporate these recommendations by connecting economic concepts and models to a pressing issue with real-world implications.

Climate change threatens the economic, social, and ecological well-being of our society and has been called the "defining problem of our age"[1] (Moon 2007, online). However, in a 2016 survey of registered voters in the United States, only half of those surveyed thought that global warming "should be a 'high' or 'very high' priority for the president and Congress" (Leiserowitz et al. 2016). Another survey of Americans found that only 57 percent of adults agreed that "global warming is caused mostly by human activities" (Marlon et al. 2018, online). In recognition of the

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importance of a climate-literate society, the National Oceanic and Atmospheric Administration (NOAA) has developed a set of climate literacy standards, stating in its mission that, "Americans' health, security, and economic well-being are linked closely to climate and weather" (National Oceanic and Atmospheric Administration [NOAA] n.d., online). With this in mind, increasing climate literacy in undergraduate curricula should be an important component of developing the next generation of consumers, voters, and decision-makers.

The teaching modules presented in this article have the dual goals of improving climate literacy in undergraduate education through polar research and enhancing student learning of economic concepts through active-learning methods. The modules are the outcome of a National Science Foundation grant awarded by the Office of Polar Programs and the Division of Undergraduate Education. The modules were conceptualized by a curriculum development team composed of an educational specialist, polar researchers, and undergraduate instructors from a range of disciplines. The outcome of the project was the creation and implementation of seven different teaching modules that have been used in a variety of courses, including thermodynamics, quantum mechanics, computer science, physics, and economics. These modules are based on the concept of computational guided inquiry (CGI), which incorporates active-learning strategies and guided inquiry within a computational platform, such as Microsoft Excel spreadsheets, Python Jupyter Notebooks, or R Studio Notebooks.

We describe two Excel-based CGI modules that can be used in a variety of undergraduate economics courses. The learning objectives of the modules are three-fold: to increase students' knowledge of climate change impacts and polar regions, to enhance student learning by applying economic concepts to real-world data, and to strengthen students' analytical and computational skills through working in Excel. The content of the modules was developed using a backward design approach that starts with the identification of the desired learning objectives of the module and the "enduring" understandings we wanted the students to come away with (Wiggins and McTighe 1998). Given the central role of models in economics, the enduring understandings for both modules focus on the students applying real-world data to an economic model or framework, identifying the key assumptions driving the results, and discussing the associated limitations of the model's outcomes. In addition to the goal of using polar research to improve climate literacy, course-specific learning objectives of the modules cover topics in standard microeconomics, environmental, urban, or cost-benefits analysis courses, including the total economic valuation framework, nonmarket valuation techniques, and principles of marginal analysis applied to marginal cost and marginal damage curves. Each module takes approximately 50 to 80 minutes to complete and can be implemented in a single class period or over multiple days. The first module focuses on estimating and graphing the expected marginal damages from regional sea level rise due to polar ice melt using data from Climate Central's Surging Seas Risk Finder Web site.[2] The module presented here specifically focuses on Tacoma, Washington, but it can be easily modified for other coastal cities. The primary prerequisite knowledge needed for students to complete this module is the concept of marginal analysis and familiarity with marginal cost and marginal damage curves. The second module is based on a partial replication of a paper from the peer-reviewed journal, *Ecosystem Services*, that estimates the total economic value of ecosystem services in the Arctic. In the module, the students' first task is to gather the relevant data from several primary sources. Then, they are guided through converting the data in Excel to get the final estimated value following the same methods used by the author of the original paper (O'Garra 2017). This module assumes students have some prior knowledge of the total economic valuation framework and would ideally follow the introduction of the topic in a course.

An assessment was conducted based on pre- and post-module surveys completed by the students to evaluate the efficacy of the CGI modules regarding climate literacy and student learning outcomes. The results in this article are based on student survey data from four different economics courses taught by three instructors who implemented the modules during the 2017–18 academic year. The findings suggest that the modules had a positive impact on student learning outcomes. Furthermore, the modules received a positive reception from the participating students and course instructors.

The remainder of this article is organized as follows: the next section reviews the educational literature on inquiry and active learning relevant to the CGI modules presented here. This is followed by a detailed description of the two modules and an in-depth discussion on implementing them in the classroom. Lastly, the results from the pre- and post-module student surveys are presented along with a brief conclusion.

Relevant literature

While much of the focus on inquiry as a pedagogical tool is concentrated in the natural sciences, it also readily applies to economics. The National Science Education Standards state that "Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations" (National Research Council [NRC] 1996, 23; Martin-Hansen 2002). In *guided* inquiry, the instructor provides data and poses questions for the students to investigate. The process involves students formulating an evidence-based hypothesis for some phenomenon, connecting their hypothesis with prior knowledge, and then communicating their findings to others (Martin-Hansen 2002). The modules presented in this article are based on the concept of computational guided inquiry (CGI) that pairs guided inquiry with a computational platform, in this case, Excel. The modules are structured to allow the students to engage with data and apply it to a framework or scenario that is either directly or indirectly connected to polar research. Through a process of guided inquiry, the students gather data to conduct the analysis, identify the underlying assumptions, and then evaluate the results.

An additional benefit of the computational element is that it involves multisensory approaches to learning in which the students actively engage with the material through a computational platform, rather than passively through a lecture, allowing students to better retain and recall information (see Barreto [2015] for more details). Excel and other computational platforms enable this kind of learning by allowing students to engage actively with data. Barreto (2009) studied student performance on an ETS economics field test by comparing the scores of students who took a conventional microeconomic theory course with those who took an Excel-based course. He found that students who used Excel regularly in the classroom and for assignments scored over six percentage points higher on the test than students in conventionally taught classes. Later, Barreto (2015) examined the literature on the use of Excel in the classroom and found that research on cognitive processes showed that multisensory inputs are more effective in encoding knowledge because students have to work with the numbers and equations in a more concrete manner, such as entering formulas into Excel and breaking down functions into their component parts. This approach is a key feature of computational guided inquiry. For example, in the sea level rise module, students must first estimate the total value of housing damages at various flood heights using housing price data and then calculate the marginal damage cost of an additional foot of flooding under different scenarios of sea level rise in Excel.

To further enhance student learning, CGI modules utilize an active-learning approach in which students are provided with an introduction to the module to review prior to coming to class. Class time is then spent working through the module under the guidance of their instructor. A number of studies have found that students perform better when having engaged in active-learning techniques in the classroom compared to more traditional lectures (Crouch et al. 2007; Deslauriers, Schelew, and Wieman 2011; Goffe and Kauper 2014; Balaban, Gilleskie, and Tran 2016). While these pedagogical approaches are commonplace in STEM (science, technology, engineering and math) courses, they are less prevalent in economics courses (Goffe and Kauper 2014), although the

Table 1. Summary of courses in which the CGI modules were implemented.

Module	Course	No. Students	Institution Type
Sea level Rise Impacts	Regional and Urban Economics	16	Liberal arts college
	Science and Economics of Climate Change	42	Liberal arts college
	Urban Economics	12	Regional state university
Total Economic Valuation of the Arctic	Natural Resource and Environmental Economics	21	Liberal arts college
	Science and Economics of Climate Change	42	Liberal arts college

Note: Students in the Science and Economics of Climate Change class completed both modules.

literature in this area is growing (Lage, Platt, and Treglia 2000; Simkins and Maier 2004; Emerson and Taylor 2004; Yamarik 2007).

In one study by Lage, Platt, and Treglia (2000), students in economics principles courses reviewed the course material prior to coming to class via videotaped lectures, voice-recorded PowerPoint slides, and/or course readings. Then, in the classroom, the instructor led the students through a hands-on activity or a lab related to the material covered for that day. Additionally, the students completed worksheets and review questions in class. At the end of the course, the majority of students reported learning more economics with the inverted classroom format that allowed for active learning and expressed a preference for it over traditional lecture formats. Similarly, Balaban, Gilleskie, and Tran (2016) found that students who engaged in hands-on problem-solving activities in a flipped classroom setting outperformed students in a more traditional lecture format across a range of measures, including knowledge, comprehension, application, and analysis.

Despite these positive findings, in a survey of economics instructors, Goffe and Kauper (2014) found that many instructors remain reluctant to incorporate active-learning techniques in the classroom, citing reasons such as large upfront costs and beliefs that "students learn best from lectures" (364). The CGI modules presented in this article aim to alleviate the first barrier by providing an off-the-shelf teaching module that can be implemented with a minimal upfront cost, and the Excel-based format provides a hands-on, active-learning experience in the classroom. While this particular project focuses on climate literacy with an emphasis on polar research, the more general approach to active learning through the use of computational guided inquiry can also be applied to a wider variety of topics and learning objectives in courses such as econometrics or macroeconomics.

Implementation and description of modules

This section describes the two Excel-based CGI modules in more detail and discusses various options for implementation. The two modules were used in four different undergraduate economics courses ranging from 12 to 42 students per class during the 2017–18 academic year (see table 1). Each module includes a set of PowerPoint (PPT) slides[3] that guide the students through the module and an accompanying Excel spreadsheet where the students input data, make calculations, and graph figures. Each module is designed to accommodate students with varying levels of experience working with Excel. The concepts in the module are scaffolded so that the students are first shown an example of how to enter the formula in Excel to complete a calculation via a screenshot in the PPT slides; then, they are directed to repeat the process for a different variable or column. The PPT slides also include several *Pause for Analysis* questions intended to guide students to reflect on the work they have just completed and think about the concepts in more depth in small groups or with a partner. Students are encouraged to work through the modules in pairs or small groups, which also provides an opportunity for peer-to-peer learning as the students discuss the questions together and compare answers in their Excel spreadsheets.

While the modules are ready to be implemented in the class with minimal preparation, they also can be tailored to fit each individual instructor's schedule and learning objectives. As written, the in-class portion of the modules requires approximately 50 to 75 minutes of class time each, depending on the pace of the students, but can be modified to accommodate a variety of class schedules.[4] Each module comprises three parts, so instructors can reduce in-class time by assigning one of the parts as a homework assignment if time is limited. The *Pause for Analysis* questions also can be modified or reduced as needed. If the module is being covered over multiple class periods, it can easily be broken up into subsections. For example, on the first day, the students could complete Parts I and II of the module followed by Part III and a wrap-up on the next day. Preparation time for the instructors mainly involves working through the module to become familiar with it, deciding how much class time to allocate, and making any modifications as desired. Working through each module takes approximately one hour. The sea level rise module requires additional time if the instructor wishes to tailor it to a different coastal city, but the additional set-up time is minimal (see more below under Module 1). We anticipate that instructors using the modules for the first time will adhere more closely to the original content provided, but as they continue to implement them in subsequent classes, they may choose to make slight modification or updates to the modules (e.g., change the *Pause for Analysis* or *Discussion* questions) to more closely align them with their own learning objectives for the course.

The PowerPoint slides for each module start with a brief introduction section to the topic that includes a climate change and polar connection with readings and questions for the students to complete before coming to class. This work is meant to provide some background information to the students in preparation for working through the module in class. An example of implementing one of the modules would typically include beginning class with a brief in-class discussion based on the module's introduction; then, the students would spend the majority of the class period working through the CGI module on their own laptops or in a computer lab (if not all students have a laptop, they can work together in pairs). While the students work on the module in class, the instructor is available for answering questions and listening in on group discussions. About 5 to 10 minutes before the end of class, the instructor reviews the *Pause for Analysis* questions and provides time for the students to discuss their findings with the class as a whole.

One of the challenges with implementing the modules, as discussed by the instructors, was that the students worked at different paces, resulting in some students finishing the work more quickly than others. One way to mitigate this problem is for the instructor to review the answers of the groups that finish first and encourage them to elaborate more or pose additional questions to them. Alternatively, the instructor can review the students' answers to make sure they are correct and direct the students to go back and make corrections as needed. For students who work through the modules more slowly, incomplete modules can be assigned as homework. To increase accountability, the students may submit their completed Excel spreadsheets via an assignment link on the course Web page, although whether they are graded or not is at the discretion of the instructor. An alternative to grading the spreadsheets themselves is to assign a follow-up written assignment that requires the students to synthesize their analysis, identify the key assumptions, report the results, and discuss the limitations. Sample assignments specific to each module are discussed in more detail in the following sections and are included with the modules (see appendix A for assignment prompts).

The modules are hosted on the SERC[5] Web site, and any updated versions will be available for download through the project homepage. Updating the modules to reflect changes in new emissions or sea level rise scenarios will primarily depend on changes or updates to the Risk Finder Surging Seas Web site that can be incorporated easily into the sea level rise modules by changing the number of houses and probabilities in the spreadsheet following the instructions for tailoring the module to any coastal region (see supplemental materials for instructions). Simple updates to the Arctic valuation module can be made by updating the purchasing power parity and inflation rate data to the current year in the Excel spreadsheet. To keep the modules relevant, instructors are also encouraged to have the students read recent news articles or publications on sea level rise or Arctic ice melt to increase student interest and connect broader climate change impacts to local issues.[6]

Module 1: Regional sea level rise impacts

This module is framed from the perspective of a city planner trying to determine how much to spend on local climate change adaptation given different scenarios of sea level rise and the associated storm surge and higher flood levels that come with it. It has been used within economics departments in two lower-level courses on urban and regional economics, as well as in an upper-level elective course on climate change. Outside of economics, the module was used in an interdisciplinary upper-level course on the science and economics of climate change with no economics prerequisite. For the urban classes, the module was implemented later in the semester following a unit on pollution, but it also could be incorporated into sections of the course focusing on future issues facing urban centers or the impact of climate change on growth and land-use management decisions. Alternatively, it could even be used in a microeconomics class to reinforce basic concepts of marginal analysis, given the comment of one instructor who implemented the module and reported that after completing the module, "one of the main learning outcomes I saw was that students really showed an improvement in thinking at the margin." The module does assume that students have had some exposure to basic economic concepts, such as marginal cost and marginal benefit curves, but as described above, it could be used to help reinforce these concepts if learning them in a class for the first time. Other concepts, such as calculating expected damages based on risk probabilities, are covered in the module.

The main calculations in the module are based on housing data provided to the students, which are used to estimate the avoided damages associated with regional flooding due to storm surge and sea level rise. It incorporates different probabilities of flooding based on four different sea level rise scenarios. While the module described here is specific to Tacoma, Washington, the data come from Climate Central's Risk Finder Web site that produces similar data for a variety of coastal cities, allowing the module to be easily tailored to different locales. The learning objectives of the module are to:

1. Increase climate literacy by connecting sea level rise due to ice melt in the polar regions to the local impacts of higher flood levels.
2. Learn tools to apply to decision-making given uncertainty in sea level rise and flooding.
3. Gain computational skills through calculating and graphing marginal damage curves in Excel.

In the introduction of the module, students become familiar with the connection of sea level rise to melting polar ice by watching a video and reading an article on the topic. Then, they are directed to the Risk Finder Web site and asked some basic questions to gain familiarity with the data they will be using in the module to conduct the analysis. During the in-class portion of the module, the instructor is provided with a brief PowerPoint presentation highlighting the different sea level rise scenarios and how they are related to polar ice melt. The students then spend the rest of the class working through the first part of the CGI module, which requires them to calculate the expected marginal damages given different probabilities of flooding in their region using median house price data[7] in Excel. As discussed above, the computational part is scaffolded to accommodate different levels of Excel experience among the students.

In the next section, the students use their results to graph the expected marginal damage curves for various levels of flooding for the years 2050 and 2100. This section gives them experience with creating graphs in Excel, including adding titles and labels for the axes. In the *Pause for Analysis* question that follows, the students are asked to analyze the figures and discuss what assumptions have been made so far and how they could contribute to the shape of the marginal damage curves.

The final section requires the students to calculate the expected damages given different probabilities of sea level rise under low, medium, fast, and extreme rise scenarios. They also graph the marginal cost curve of a proposed sea wall relative to the marginal expected damages of flooding. In this final graph, students are confronted with the familiar graph of a marginal cost curve and a marginal avoided damage (or marginal benefit) curve. Using this graph, the students can make a recommendation about what the "optimal" (or efficient) seawall height would be given the expected marginal damages from flooding.

While the analysis is very basic with many simplifications, one of the enduring goals of the exercise is for students to understand the importance of making assumptions in economic modeling. Thus, the final set of *Pause for Analysis* questions focuses on the assumptions and limitations of the analysis (e.g., only using housing values to estimate damage costs or assuming that the total value of the house is lost with one foot of flooding) and encourages the students to think about how changing these assumptions would impact their results. Through this exercise, students begin to comprehend the broader role of models in economics, along with their limitations and the implications of the underlying assumptions. Furthermore, students working in Excel are able to quickly calculate marginal costs from total costs, and then graph the curves to see how the theory applies to real-world empirical data. For example, the economics of pollution is often taught with an upward-sloping, monotonic marginal damage curve, suggesting that as pollution emissions increase, marginal damage costs also increase. However, when this model is applied to marginal flood damages in Tacoma, Washington, the students find that the marginal damage curves do not follow the expected upward trajectories. Therefore, the students are forced to revert back to the data and the underlying assumptions of the model to understand why this may be the case.

Finally, instead of grading each Excel spreadsheet, an optional follow-up assignment is to have the students write a memo to the city planning department that summarizes the analysis and results, identifies the main limitations, and provides a policy recommendation (the assignment prompt is included in the module). This assignment requires the students to synthesize and condense the multiple tables and graphs they compiled throughout the module into a single summary document that highlights the key features of the analysis and requires the students to convey economic concepts to a nontechnical audience in writing.

Module 2: Total economic valuation of the Arctic

The second module is based on replicating a paper published in the peer-reviewed journal, *Ecosystem Services,* entitled "Economic value of ecosystem services, minerals and oil in a melting Arctic: A preliminary assessment" by O'Garra (2017). It assumes that the students are already familiar with the total economic valuation (TEV) framework and nonmarket valuation techniques, such as contingent valuation and benefits transfer, which are standard topics for an environmental economics or cost-benefit analysis course. Ideally, the module would follow the introduction of these topics as an applied application of the TEV framework, nonmarket valuation, or both. The learning objectives of this module are to:

1. Increase climate literacy by engaging in academic research based on the value of lost ecosystem services in the Arctic associated with climate change.
2. Apply the TEV framework to estimate the annual value of the Arctic and identify the key assumptions made in the estimation and how they impact the final value.
3. Employ economic and computational skills in Excel, including adjusting for inflation, converting currency, and tabulating and organizing data.

The pre-class assignment includes reading the paper that will be replicated (6 pages) and completing the *Introduction* section of the module, which briefly introduces the Arctic region and the predicted changes in temperature and precipitation given different climate scenarios. In class, the students start with the first part of the module that identifies four papers and reports used in O'Garra (2017) and guides the students through extracting and recording the relevant data from each source in Excel.

After the key data have been collected (e.g., replacement costs of subsistence hunting in the Arctic, household willingness-to-pay for polar bear conservation, etc.), the next part requires the students to convert the values to get the annual total economic value for each component. For example, they have to use the *household* stated preference value for polar bear conservation from Olar et al. (2011) to estimate the *per capita* value for Canada, and ultimately the total annual value for the Arctic. Similar to the previous module, the calculations are scaffolded in Excel to accommodate different levels of experience. Once all of the values have been estimated, in the final part of the module, the students convert the Canadian currency to U.S. dollars based on purchasing power parity and adjust for inflation. In this section, they use the appropriate conversion rates to get a final estimate of the annual value of ecosystem services in the Arctic updated to 2018 USD.

In addition to exposing the students to empirical research that employs nonmarket valuation techniques, another key feature of the module is that it requires the students to apply the same assumptions that O'Garra used in her analysis (e.g., households have 1.5 people). This requirement enables the students to assess the validity of these assumptions and analyze how they impact the final estimated value, which is a focus of the *Pause for Analysis* and *Discussion* questions. The final discussion questions aim to get the students to focus on other potential limitations to the analysis and the challenges associated with this type of environmental valuation. Follow-up assignments for this module could include having the students write a memo summarizing their analysis to a local policymaker. Alternatively, a more advanced assignment would be having the students identify a potential missing value not accounted for in the O'Garra (2017) paper (e.g., existence values for other Arctic wildlife or the value of carbon sequestration in the Arctic tundra) and then finding an academic source to get an estimate of the missing value and incorporating it into an update of the total economic value of the Arctic, written up as an addendum to the original paper (an optional prompt for this assignment is included in the module).

CGI module evaluation and assessment

To assess the learning objectives identified for the project, we had the students complete pre- and post-module surveys asking them questions about their comfort with Excel, their prior experience with polar research, and their opinions on climate change. They were also presented with a graphical figure (different for each module) and were given the following prompt: "Ask two questions about this visual representation" (see figures 1 and 2). Then, in the post-module assessment surveys, the students were shown the same figure again and asked to write two more questions about it. The time between pre- and post- surveys varied by the instructors who implemented the modules, but was typically one week. The figures selected were tangentially related to the topics covered in the module, but the objective was for the module to not directly impact the student's ability to interpret the figures, although it may influence the content of their questions. The surveys were presented to the students as a way to get feedback on the project for the NSF grant and did not impact the students' grades in any way.

The motivation for using this question-driven approach came from discussions with an educational specialist on methods for assessing the modules as a student-learning intervention. Student-generated questions have been identified in the educational literature, particularly in the natural sciences, as a measure of students' conceptual and cognitive understanding, as well as

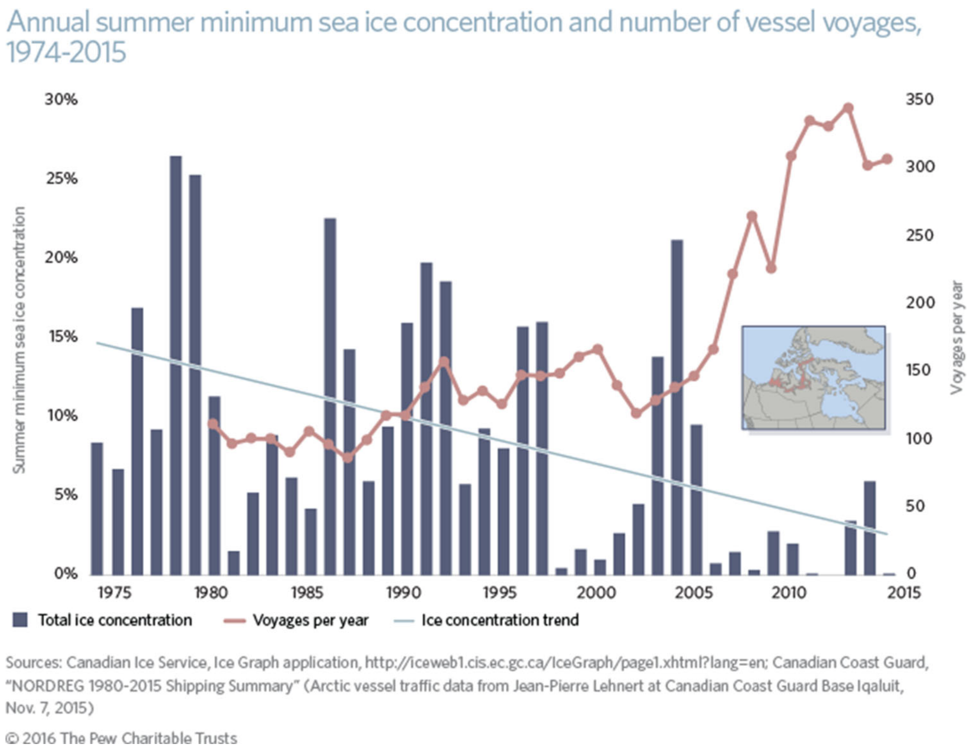

Figure 1. Student survey figure for TEV module student question generation.

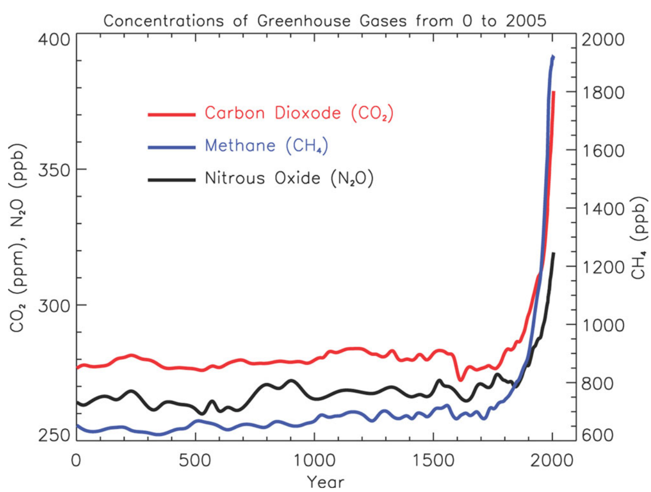

Figure 2. Figure for the sea level rise module student question generation survey.

using the sophistication of the question as a proxy for basic problem-solving skills (Dori and Herscovitz 1999; Gautier and Solomon 2005). Our hypothesis is that in the process of completing the CGI module, students not only learn the topic-specific component of the module that fulfills the learning objectives of the course but also improve their critical thinking and analytical skills that could be transferred to other, nonrelated concepts through their experience of working with and applying real data to theoretical economic models and frameworks. We test this hypothesis by comparing the questions from the survey written by the students before they did the module

Table 2. Rubric for ranking questions on testability.

Score	Criteria and Sample Questions
1	Not relevant to testability a. No reference to physical world (about the visual meaning of colors, etc.). b. Question is too unclear to be testable. c. Not answerable with the scientific method because too unclear about what variables could be tested. Sample questions • What am I looking at? • How was this data gathered? • Why are voyages per year increasing so much?
2	Question references physical world but is not testable with the scientific method. a. Not answerable, perhaps because it is unspecific, shows an incorrect understanding of the figure, or is too unclear. b. Answerable, but scientific method is not needed. c. The figure already answers the question. d. Possibly a specific question referring to the figure but too broad to answer with the scientific method. Sample questions • What is the trend in Artic sea ice volume change? • What caused the spike in ice cover around 2004? • What is the average of summer minimal sea ice concentration?
3	Question is testable with the scientific method. a. Empirical question about the physical world. b. Specific references to the visual. Sample questions • What causes the cyclical nature of the ice concentration to decline? • What environmental factors allow a year to have below average ice in one season but above average ice in another? • Is the Ice concentration trend directly correlated to the number of voyages per year?

with the questions they wrote after they completed it, with both the pre- and post- questions referring to the same graph (figures 1 and 2). We use two different approaches for the analysis. The first is a top-down approach, in which a rubric is used to score the students' questions based on their level of testability (see table 2), and the results are analyzed using OLS regression analysis. For the second approach, we followed the methods of Ryken and Hamel (2016), using a process based on grounded theory to analyze the questions from a more qualitative, bottom-up perspective. This approach involved a team of three people analyzing sets of questions that were written by the same student from their pre- and post-module surveys. The team looked for shifts that emerged from the pre- to the post-survey questions that exhibited some form of positive growth or change by the student.

We recognize that the relatively short engagement that students have with the modules (typically one week or less) and the brief time elapsed between the pre- and post- surveys may not allow for appreciable gains in student learning. However, the results from the assessments presented here are positive and suggest that the students did experience some measurable growth based on the evaluations of their questions. The regression results indicate that the CGI module improved students' ability to generate "testable" questions, and the grounded theory approach suggests that the level of questions written by the students progressed from more basic or one-dimensional questions written in the pre-assessment survey to more detailed and multi-dimensional questions in the post-assessment survey.

Regression results from top-down analysis

As part of the pre- and post-module surveys, students were asked to generate a total of four questions (two pre- and two post-) based on the figure presented to them that differed for each module. Using a top-down approach, the questions were then ranked on a scale of 1 to 3, based on a rubric defining various levels of "testability" (see table 2). To test the robustness of the rubric, a random sample of 20 percent of the questions was double-coded and achieved a 76 percent agreement.[8] The selection of the testability criterion was based on a preliminary assessment of the questions generated by students who completed a CGI module from a different course.[9] Students

Table 3. Questions in pre- and post-assessment survey and associated value scale.

	Survey Questions		
Scale	How comfortable are you with Excel?	In your opinion, to what degree are human activities contributing to climate change?	How important do you think polar research is in the context of climate change?
1	Very uncomfortable	Not at all	Not important at all
2	Somewhat uncomfortable	Slightly	Slightly important
3	Neutral	Moderately	Moderately important
4	Somewhat comfortable	Significantly	Very important
5	Very comfortable	–	Extremely important

were also asked questions regarding their comfort level with Excel and opinions on climate change and polar research to evaluate the other project goals regarding climate literacy, familiarity with polar data, and improved computational skills (see table 3). The survey results, together with the testability scores, were compiled into a panel dataset of pre- and post-module responses, along with socio-demographic data on the students (see table 4). Out of the 91 total students registered in the four classes in which modules were implemented, 90 percent of the students completed some portion of the pre- or post- survey. However, in the final analysis, a number of observations were dropped due to incomplete data. For example, some students filled out the pre-module survey but did not complete the post- survey. Other students started the survey but did not complete all the questions in one or both of the surveys. If students did not provide four questions across both surveys, they were not given a testability score by the evaluators. The final sample size used in the regression analysis includes 64 students or 70 percent of all students registered in the four courses.

To analyze the results, we use OLS regression analysis to compare the students' questions and survey responses before and after they completed the CGI module. The answers to the survey questions, along with the testability scores, serve as the dependent variables in the regression models, and the main independent variable of interest is the dummy variable, *post*, which is an indicator for survey responses from the post-module survey. The regression results are displayed in table 5. The results indicate that completing the CGI module improved the students' ability to ask more "testable" questions, as defined by the rubric. The coefficient of the *post* variable indicates that after the module, testability increased by almost one unit after controlling for instructor, module type (TEV or SLR), race, gender, and whether the student is a STEM major. While the coefficient value for *post* is not directly interpretable, the results are statistically significant and suggest that the students improved their ability to ask more advanced questions after completing the CGI module.

Other results indicate that working through the module did not increase students' level of comfort with Excel spreadsheets. The lack of perceived improvement in Excel skills is somewhat surprising. Some students initially responded being "somewhat comfortable" using Excel in the pre-module survey response, but changed their post-module survey response to "neutral" or even "somewhat uncomfortable," suggesting that the module may have exposed some weaknesses in their Excel skills, which is reflected in these results. For the survey question that asks students to rank the degree to which they think humans are contributing to climate change, the post-module coefficient is not statistically significant. However, in the pre-module survey, 95 percent of the students indicate that they think human activities are "significantly" contributing to climate change, so there is little room for movement. Not surprisingly, upon completion of the module, students felt that polar research was more important in the context of climate change based on the positive and statistically significant coefficient for *post* in column (4) of table 5.

Table 4. Summary statistics for post-module survey results.

Variable	Percentage	Total Obs.
Male	0.501	64
White	0.762	64
Black	0.0476	64
Asian	0.159	64
Latino/a	0.111	64
Other	0.032	64
STEM major	0.333	64
Public university	0.095	64

Note: Total observations refer to the number of students who completed all components of both the pre- and post-module surveys and were included in the final regression analysis.

Table 5. Panel regression results for various dependent variables.

	(1) Testability		(2) Excel Comfort		(3) Human Impact		(4) Polar Import	
Variable	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
"Post"	0.75***	0.08	−0.06	0.12	0.03	0.02	0.16**	0.07
TEV module	−0.09	0.09	0.49**	0.22	−0.006	0.005	−0.01	0.08
Instructor 1	−0.08	0.12	0.88***	0.32	−0.05	0.06	−0.14	0.18
Instructor 2	0.11	0.13	−0.13	0.68	−0.02	0.16	−0.03	0.23
Male	0.12	0.08	−0.33	0.23	−0.13**	0.06	0.15	0.13
Black	−0.01	0.14	0.17	0.38	−0.20	0.28	−0.95***	0.28
Asian	0.04	0.10	0.26	0.26	0.03	0.04	−0.07	0.13
Hispanic	0.07	0.13	0.09	0.27	−0.07	0.08	−0.46	0.32
STEM major	0.21**	0.09	0.50**	0.22	0.05	0.04	0.28**	0.13
Constant	1.82***	0.12	3.49***	0.24	3.97***	0.04	4.25***	0.12
Total obs.	263		168		167		160	
No. students	64		66		66		62	
R-squared	0.272		0.153		0.134		0.217	

Note: Standard errors are clustered at the student level. For column (1) the unit of observation is the student's response to the survey questions. In the Science and Economics of Climate Change course the same students completed both modules and thus were surveyed twice, one time for each module or 8 questions total per student. All other students wrote 4 questions each. Columns (2)–(4) refer to the following survey questions: How comfortable are you with Excel?; In your opinion, to what degree are human activities contributing to climate change?; and, How important do you think polar research is in the context of climate change?

Grounded theory assessment from bottom-up analysis

The second assessment approach is based on grounded theory, which seeks to use the data as a starting point for the analysis to see what patterns and trends emerge, rather than starting with a preconceived theory or framework such as a rubric (for more on grounded theory, see Charmaz [2006]). For this analysis, a team of three people individually analyzed the pre- and post-survey questions grouped by student from one class that completed the sea level rise module. Of the 21 students who completed both the pre- and post- surveys, questions from 18 of the students were included in this analysis. The questions from the other three students were dropped due to missing data. A complete set of questions by any individual student included two pre-survey questions and two post-survey questions for a total of four questions per student. The questions used in the analysis are based on the graph in Figure 1. In this assessment, each of the three people looked for common patterns or themes in which the questions could be categorized.

Categories that emerged included time-oriented questions that refer to specific years, and one-dimensional versus multi-dimensional questions based on the number of variables contained in the question. An example of a one-dimensional student question is, "What is the general trend for ice concentration?" An example of a multi-dimensional question is, "What is the relationship between total ice concentration and voyages per year?" After each person separately coded the questions based on the categories that emerged, pairings of questions written by the same student were examined to determine if a "shift" took place from the pre- to the post-module survey questions. Of the 18 sets of student questions, the team collectively agreed that 8 students displayed a

Table 6. Sample pre- and post-module survey questions from grounded theory analysis.

No.	Survey	Questions	Analysis
1	Pre	Why does voyages per year rise sharply after 2005? How would this information look different if presented seasonally?	The post- questions display a shift to more open questions, making connections to outside factors.
	Post	What other factors converged in 1990 that led to voyages overtaking melting sea ice? How does factors [sic] further hinder sea traffic as the ice melts?	
2	Pre	Why are voyages per year significant? Why is sea ice significant?	The post- questions make connections to outside circumstances while the pre- questions are focused on orienting to the figure.
	Post	When is summer sea ice expected to be 0? How have ecosystems changed with the decrease in sea ice?	
3	Pre	Why is there a sharp increase in the number of vessel voyages? Why does the total ice concentration vary so much between certain years?	There seems to be no difference in the quality or complexity of questions from the pre- to post- survey.
	Post	Why does voyages per year increase as ice concentration falls? Why is there a sharp decline in ice concentration after 2004?	

positive shift, indicating that their questions in the post-assessment survey could be considered more advanced or evolved.

Table 6 shows three examples of student questions from the pre- and post- surveys. Two examples were identified by the team as representing a positive shift in question generation, and one example displays no change in the level or complexity of questions asked by the student. In the first two examples, the students' questions shift from being one-dimensional in the pre- survey, focusing solely on the figure, to multi-dimensional questions in the post- survey that engaged external factors such as the ecosystem or other factors affecting voyages. In the third example, there is no discernable difference between the questions in the pre- and post- surveys. Among 18 sets of questions analyzed in this manner, 8 sets (or 44%) displayed a shift to a more complex or higher-order question, which we believe is a positive outcome given the relatively short duration the students engaged with the module. These findings also support the empirical results from the regression analysis that students asked more "testable" questions after completing the module.

Conclusion

The objective of the CGI modules introduced in this article is to walk students through exercises that apply polar research and related data to economic models with the ultimate goal of increasing climate literacy. Additionally, the modules highlight the important role that assumptions play in economic modeling and provide insight into both the limitations of the models, as well as their usefulness in a policy setting. The CGI framework presented here aims to provide students with practical skills such as data manipulating and analysis, while at the same time allowing instructors to achieve learning objectives specific to their course and enhancing the student learning experience by incorporating more active learning in the classroom.

Notes

1. United Nations Secretary General Ban-Ki Moon made this statement in his speech at the United Nations Conference on Climate Change in Bali in 2007.
2. Climate Central is a nonprofit organization that conducts research on climate change impacts due to sea level rise and flooding in coastal cities. Web site: https://riskfinder.climatecentral.org/

3. The format of the original CGI modules the students completed in this study was in Microsoft Word with an accompanying Excel spreadsheet. They have since been reformatted to PowerPoint slides to improve the user interface. The main content and text of the modules remain the same.
4. Among the three instructors who implemented the sea level rise module, one completed it over two 50-minute class periods, another did it in one full 80-minute class, and the third completed it during one 2-hour class.
5. SERC refers to the Science Education Resource Center at Carleton College, and is home to a large collection of educational resources. Web site: https://serc.carleton.edu/penguin/
6. Articles on sea level rise and its impacts are becoming more and more common in the news. For example, a quick news search on “sea level rise” finds a number of articles, including “$50 billion worth of Bay Area homes at risk of rising seas by 2050, says report” from *The Mercury News* on July 31, 2019, and “Record Heat Threatens Greenland’s Ice Sheet” from the *Pacific Standard* on July 30, 2019.
7. House price data comes from ESRI’s ArcGIS interactive Web site with 2012 data for USA median home values. Web site: https://www.arcgis.com/home/webmap/viewer.html?useExisting=1&layers=8abd47c2988d497a8f24ad89180980c8
8. The “testability” assessment was conducted for all modules developed for the NSF project. The total sample size of student questions from all modules implemented in both science and economics courses is 666.
9. The students completed a CGI module on rovibrational waves that was part of a course in atmospheric chemistry. Among the various criteria considered for evaluating the questions from this module, including sophistication, clarity, engagement, and synthesis, testability was the only one that showed a statistically significant difference between pre- and post-question scores after a subset of the questions was ranked by three different evaluators.

Acknowledgment

The authors thank Amy Ryken for her guidance and assistance with the grounded theory analysis.

Funding

This work was supported by the National Science Foundation under Grant 271033.

References

Balaban, R. A., D. B. Gilleskie, and U. Tran. 2016. A quantitative evaluation of the flipped classroom in a large lecture principles of economics course. *Journal of Economic Education* 47 (4): 269–87. doi: 10.1080/00220485.2016.1213679.

Barreto, H. 2009. *Intermediate microeconomics with Microsoft Excel*. New York: Cambridge University Press.

——— 2015. Why Excel? *Journal of Economic Education* 46 (3): 300–9.

Becker, W. E. 2004. Economics for a higher education. *International Review of Economics Education* 3 (1): 52–62. doi: 10.1016/S1477-3880(15)30145-6.

Charmaz, K. 2006. *Constructing grounded theory: A practical guide through qualitative analysis*. Thousand Oaks, CA: Sage Publications.

Crouch, C. H., J. Watkins, A. P. Fagen, and E. Mazur. 2007. Peer instruction: Engaging students one-on-one, all at once. In *Research-based reform of university physics*, ed. E. F. Redish and P. J. Cooney. *Reviews in Physics Education Research* 1 (1). College Park, MD: American Association of Physics Teachers.

Deslauriers, L., E. Schelew, and C. Wieman. 2011. Improved learning in a large-enrollment physics class. *Science* 332 (6031): 862–64. doi: 10.1126/science.1201783.

Dori, Y. J., and O. Herscovitz. 1999. Question-posing capability as an alternative evaluation method: Analysis of an environmental case study. *Journal of Research in Science Teaching* 36 (4): 411–30. doi: 10.1002/(SICI)1098-2736(199904)36:4<411::AID-TEA2>3.0.CO;2-E.

Emerson, T. L. N., and B. Taylor. 2004. Comparing student achievement across experimental and lecture-oriented sections of a principles of microeconomics course. *Southern Economic Journal* 70 (3): 672–93. doi: 10.2307/4135338.

Gautier, C., and R. Solomon. 2005. A preliminary study of students’ asking quantitative scientific questions for inquiry-based climate model experiments. *Journal of Geoscience Education* 53 (4): 432–43. doi: 10.5408/1089-9995-53.4.432.

Goffe, W. L., and D. Kauper. 2014. A survey of principles instructors: Why lecture prevails. *Journal of Economic Education* 45 (4): 360–75. doi: 10.1080/00220485.2014.946547.
Hansen, W. L., M. K. Salemi, and J. J. Siegfried. 2002. Use it or lose it: Teaching literacy in the economics principles course. *American Economic Review* 92 (2): 463–72. doi: 10.1257/000282802320191813.
Kvam, P. 2000. The effect of active learning methods on student retention in engineering statistics. *The American Statistician* 54 (2): 136–40. doi: 10.2307/2686032.
Lage, M. J., G. J. Platt, and M. Treglia. 2000. Inverting the classroom: A gateway to creating an inclusive learning environment. *Journal of Economic Education* 31 (1): 30–43. doi: 10.1080/00220480009596759.
Leiserowitz, A., E. Maibach, C. Roser-Renouf, S. Rosenthal, and M. Cutler. 2016. *Politics & global warming*. Yale University and George Mason University. New Haven, CT: Yale Program on Climate Change Communication.
Marlon, J., P. Howe, M. Mildenberger, A. Leiserowitz, and X. Wang. 2018. *Yale climate opinions maps 2018*. New Haven, CT: Yale Program on Climate Change Communication. https://climatecommunication.yale.edu/visualizations-data/ycom-us-2018/?est=human&type=value&geo=national. (accessed September 2, 2019).
Martin-Hansen, L. 2002. Defining inquiry: Exploring the many types of inquiry in the science classroom. *The Science Teacher* 69 (2): 34–37.
Moon, B.-K. 2007. United Nations Climate change conference. Speech, Bali, Indonesia, December 12. *The Guardian*. https://www.theguardian.com/environment/2007/dec/12/bali.climatechange1. (accessed September 2, 2019).
National Oceanic and Atmospheric Administration (NOAA). n.d. About NOAA climate.gov: Mission. *NOAA Climate.gov*. https://www.climate.gov/about. (accessed July 9, 2019).
National Research Council (NRC). 1996. *National science education standards*. Washington, DC: National Academies Press.
O'Garra, T. 2017. Economic value of ecosystem services, minerals and oil in a melting Arctic: A preliminary assessment. *Ecosystem Services* 24 (April): 180–86. doi: 10.1016/j.ecoser.2017.02.024.
Olar, M., J. Louvel, M. Hernandez, C. Sauve, S. Zussy, and J. Messier. 2011. *Evidence of the socio-economic importance of polar bears for Canada*. Ottawa, Canada: Government of Canada.
Ormerod, P. 2003. Turning the tide: Bringing economics teaching into the twenty first century. *International Review of Economics Education* 1 (1): 71–79. doi: 10.1016/S1477-3880(15)30212-7.
Ryken, A. E., and F. L. Hamel. 2016. Looking again at "surface-level" reflections. *Teacher Education Quarterly* 43 (4): 31–54.
Salemi, M. K. 2005. Teaching economic literacy: Why, what and how. *International Review of Economics Education* 4 (2): 46–57. doi: 10.1016/S1477-3880(15)30132-8.
Simkins, S., and M. Maier. 2004. Using just-in-time teaching techniques in the principles of economics course. *Social Science Computer Review* 22 (4): 444–56. doi: 10.1177/0894439304268643.
Walstad, W., and S. Allgood. 1999. What do college seniors know about economics?. *American Economic Review* 89 (2): 350–54. doi: 10.1257/aer.89.2.350.
Wiggins, G., and J. McTighe. 1998. What is backward design. *In Understanding by Design, G. Wiggins* 13–34. Alexandria, VA: Association for Supervision and Curriculum Development.
Yamarik, S. 2007. Does cooperative learning improve student learning outcomes? *Journal of Economic Education* 38 (3): 259–77. doi: 10.3200/JECE.38.3.259-277.

Appendix A

Assignment prompts

Sea level rise module memo assignment

Suppose that you were hired by the City of Tacoma to conduct an analysis of the impacts and potential damages of impending sea level rise in Tacoma. For this assignment, you now need to synthesize the information and data you have analyzed while working through the module into a 2- to 3-page memo (including figures) to the director of the City of Tacoma's Office of Environmental Policy and Sustainability. You can check out the mission of the department at their Web site, https://www.cityoftacoma.org/cms/one.aspx?objectId=18996.

The memo should briefly outline the problem, describe how you conducted the analysis, your results, limitations of the results, and a recommendation for action. For direction on the format of a memo, check out this Web site, https://owl.purdue.edu/owl/purdue_owl.html, for detailed guidelines.

Total economic valuation module paper addendum assignment

An addendum is an item of additional material added at the end of a book or other publication. For this assignment, you will write an addendum to the O'Garra (2017) paper for the journal *Ecosystem Services* that will include a revised estimate of the TEV of the Arctic based on your research that includes an additional component in the valuation calculation. For example, you could include the existence value of penguins, or another species native to the Arctic, the value of research conducted in the Arctic, or other missing values you've identified in the current paper.

To conduct your revised calculation, you must find a research article that provides an estimate of the missing value you intend to include, and then you will convert the values found in that paper to the Arctic as a whole, similarly to what you have done in this module.

The addendum should include the following components:

- An Introduction explaining why the current estimated value in the paper is not sufficient and how you propose to update the calculation.
- A description of the added primary data source (research paper, journal article, etc.) used in your updated valuation.
- A description of the process by which you converted the data from the primary source to fit in with the estimate for the annual total economic value, including a table of your conversions and relevant sources as appropriate.
    - This description should include a discussion of any assumptions you made in the calculation of your added value and the potential limitations of these assumptions.
- Results and discussion where you report to revised annual TEV of the Arctic and why this estimate is important from a policy perspective.