



Improving student comprehension through interactive model visualization

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ABSTRACT

A large literature has shown that novices and experts across the STEM disciplines differ markedly in how they approach and solve problems. Many STEM education scholars find that giving students scaffolded exercises in which they work with a visualization tool can be highly effective in teaching novices to think more like experts. Using model visualization software developed for EconGraphs, we have created three custom collections of interactive exercises for use in microeconomics courses at three institutions, two in the US and one in the UK. Based on surveys of the students ($n=71$, 167, and 57 respectively at the three institutions), students found the new exercises helpful. Additional analysis at two of the institutions suggests that the exercises were more likely to be valued by students with weaker math skills, students with weaker introductory microeconomics skills, and, in some cases, students who agreed that economics was interesting and applicable to their daily lives. The contributions of this paper are to illustrate how the free content from EconGraphs and the associated authoring tools may be used to create exercises that enhance the teaching and learning experience at a range of institutions; to provide the exercises themselves as a public good; and to invite further innovation and investigation in this area.

1. Introduction

Our discipline has a problem with teaching microeconomic theory. Many students dislike microeconomics, struggle to see its relevance in the wider curriculum, and feel alienated by the content.¹ This alienation can further exacerbate issues around diversity, equity, and inclusion in economics in part because the preferences of women in economics may differ from those of male economists on average, the perceptions of economics by students of color, and the perceptions of economics by first generation or lower-income students (May et al., 2014; Bayer and Rouse, 2016; Avilova and Goldin, 2018; Livermore et al., 2020; Francis et al., 2022).

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¹ This may be unsurprising if we understand the trajectory from first-year microeconomics, with there being challenges for similar reasons and related issues with diversity in economics, see Bayer et al. (2020a).

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Intermediate microeconomics, which is often taught as a chalk-and-talk subject, often does an imperfect job addressing the cognitive challenges of learning that students confront (Chew and William, 2021).² It is little wonder that students who enter their university studies enthusiastic about economics often experience a drop-off in that enthusiasm over the course of their studies (McKee et al., 2023).

One source of this problem is the fact that novices and experts differ markedly in how they approach and solve problems. This is not specific to microeconomics, or even economics: a large literature (e.g., Sherin, 2010; Larkin et al., 1980; Eichenlaub and Redish, 2018) has documented this across STEM disciplines. A central challenge lies in the use of mathematics to model phenomena: Students who struggle with the mathematics of a model face a cognitive burden that prevents them from engaging with the model itself. Orlov et al. (2021) show empirically that mathematical skills measured at the beginning of the term are strong predictors of success in both introductory and intermediate-level economics courses.

Education scholars studying STEM (e.g., Dreyfus and Halevi, 1991; Hegedus and Kaput, 2004) have found that giving students scaffolded exercises in which they work with a visualization tool can be highly effective in teaching novices to think more like experts. Such visualization tools have grown in popularity in the teaching of economics over the past two decades. Kaufman and Kaufman (2002) were pioneers when they created interactive graphics on the website ThinkEconomics for teaching introductory economics, and Varian (1996) introduced Mathematica to economists for the practice of economic research. Mathematica has also been used in a variety of economic educational contexts typically showing individual applications, such as models of duopoly or strategic interaction with interactive graphs to demonstrate how the models work (Eckalbar, 2002; MacLachlan et al., 2009; Pezzino, 2016). Other authors have advocated similarly for the use of Maple for interactive graphics (Raymond et al., 2008) and for adaptive multiple-choice quizzes with the use of interactive graphics (Pezzino, 2018). And of course, publishers and other commercial enterprises have made interactive demonstrations part of their offerings, most commonly at the Principles level.

However, all of these tools presented challenges related to student accessibility. Mathematica is a proprietary programming language, Mathematica demonstrations are not open source, and one cannot access Mathematica without a paid license. Publisher material is available only to students who purchase material, and is not available to students who buy a used book, exacerbating inequalities in the classroom. And, while open source programming languages like R and Python have become more commonly used to teach graphing, visualization, and interactivity (Dvorak et al., 2019; KurokiMasanori, 2021; Luedtke, 2023), these involve students learning programming languages or downloading specialized software to their computers. Effectively, they replace one cognitive burden (doing the math) with another (computer programming).

To solve this problem of accessibility, one of us (Makler) set out in 2014 to provide a framework to create interactive graphs that can run in any modern Internet browser, without the need for any supplemental software. All code used to generate them is open-source and published under licensing rules that allow anyone to freely create derivative works, and the code and an authoring interface for creating graphs are published at kineticgraphs.org. More than 300 graphs authored using these tools are available on the web site econgraphs.org. The graphs published on that site were designed for use as standalone demonstrations during lecture, or within narrative explanations of models in an interactive textbook. There were no assessment questions linked to the graphs, and consequently little guidance to students for how they might use them to gain a deeper understanding of the models they represented.

The purpose of this project, therefore, is to develop a novel use of the graphs within the context of student assessment and learning. Using a combination of existing graphs from EconGraphs and new graphs produced using the authoring interface on KineticGraphs, we created three sets of interactive exercises for use in microeconomics classes at three institutions (two in the US and one in the UK). We will refer to these institutions as A, B, and C throughout the paper. While each of these courses uses calculus, many (if not most) of the exercises we have developed would be useful in courses that do not use calculus. The exercises are available at https://www.econgraphs.org/projects/iree_exercises. Adopting practices advocated in the learning sciences and based on evidence from STEM education, we implement exercises with the interactive graphs so that a student may overcome misconceptions they have of how models work, address having insufficient prior knowledge of algebra, and transfer knowledge of algebra and calculus to economic intuition through the use of the interactive graphs.

We surveyed students about the perceived impact of the interactive graphs and exercises on their learning. For example, we asked if students felt that the interactive visualization exercises helped them to better understand the course material. Each class was surveyed at different points in the semester, and, at two of the institutions, demographic data about the students was also collected and used in the analysis. Using administrative data as well as data on the students' perceptions of the usefulness of economics,³ we conduct regression analysis to understand the correlates of whether students find the interactive graphs useful for their learning. We pair the analysis with in-depth discussion of the students comments on the usefulness of the interactive graphs from open-ended questions.

Our results suggest that a majority of students enjoyed the interactive graphs and found them somewhat helpful or very helpful. Student comments and beginning-of-term assessment data that we examined in conjunction with the survey responses suggest that students who are less confident in their mathematical ability are more likely to find the interactive graphs helpful. Furthermore, additional data from Institution C suggests that female students and students who think economics is interesting (or who think about economic events in their day-to-day life) are more likely to find the interactive graphs helpful.

² Asarta et al. (2021) show that most introductory economics courses are taught with chalk and talk, while Harter and Asarta (2022) show the same is true in intermediate and advanced economics courses. Allgood et al. (2015) also suggest that the majority of undergraduate economics courses are taught with lecture-style instruction.

³ At Institution A, these perceptions were measured at the beginning of the term while at Institution C they were measured in the middle of the term.

Our contribution is threefold. First, we demonstrate that it is possible to create rich assessment items based around interactive graphics using freely available tools; and we provide preliminary evidence that suggests that such exercises may benefit students. Second, we provide the exercises themselves as a public good for other instructors to adapt to their teaching, and we advocate for the creation of more such exercises to be developed. Finally, we discuss the opportunities and challenges we faced in fielding a multi-site pilot intervention to understand the benefits of these tools in economics education.

We proceed as follows. In [Section 2](#), we outline the main ways we used the interactive graphs and demonstrate their use in each of the three institutions. We proceed, in [Section 3](#), to a discussion of the results from our student feedback including the analysis of numerical responses from the students as well as including relevant comments from the student feedback. Additional regression analysis from the sample of students at Institutions A and C is available in [Section 4](#). We conclude with a discussion in [Section 5](#).

2. Using interactive graph-based exercises in economics

Beginning in 2015, a website called EconGraphs (<https://www.econgraphs.org>) started publishing a collection of interactive graphs, mostly (but not exclusively) on topics in intermediate microeconomics. All the code generating the graphs was developed from open-source code libraries published under MIT or similar licenses, allowing the development of derivative works. No login to EconGraphs is needed, and no data is collected from users. Each page on the site contains either a standalone graph or a page of text with embedded graphs. Pages may be accessed via a simple URL or embedded in other web sites, such as html slides—for example, slides.com—allowing them to be used fluidly in a class setting.

For the first several years of EconGraphs' development, they were only used as tools for classroom demonstrations, operated by the lecturer; the graphs themselves were then made available to students to “play with” on their own. While providing access to graphs may be useful, it might not be enough to ensure meaningful learning. We believe that simply presenting graphs to students during lectures may have limited effectiveness in promoting a deep level understanding. Indeed, prior to our work, course evaluations in courses at Institution B provided criticism that while students had access to the graphs as part of the class slides, they did not know what they should do with them on their own, and sometimes had difficulty understanding what the lecturer was doing with the graphs in class.

By contrast, providing students with opportunities to engage with the material through experiments or activities is found to be much more effective in promoting long-term retention and understanding of concepts than simply showing students interactive demonstrations. Studies in physics ([Eichenlaub and Redish, 2018](#); [Dhanapal and Wan, 2014](#)) have found that when students are given the opportunity to actively participate in hands-on experiments, they increase their participation in class as well as report a higher level of intrinsic motivation for learning. In middle school mathematics, [Roschelle et al. \(2010\)](#) conducted a randomized controlled trial on the use of educational software called SimCalc, in which interactive graphs and simulations were shown to be much more successful in promoting learning gains when paired with guided exercises in the form of workbooks that walked students through a carefully-designed path. They conclude that “less emphasis should be placed on the value of technology alone and more on interventions that deeply integrate professional development, curriculum materials, and software in a unified curricular activity system.”⁴

Randomized controlled trials do not exist in economics on the use of interactive graphs.

While we have not conducted an RCT, we consider our paper to be a helpful multi-site initial exploration of how to start thinking about the use of interactive graphs in intermediate microeconomics teaching. Building on the conclusions of [Roschelle et al. \(2010\)](#), we focused our work on the development of exercises that guide students in a way which provides them support, such as clear instructions or guidance on how to interpret and analyze the data, to help them fully benefit from graph-based instruction.

In the academic year 2022–2023, we incorporated exercises in different ways in intermediate microeconomics courses at the three institutions. Below we discuss the details of each institutional context and give examples of the exercises we used.

2.1. Institution A

Institution A is a statutory R1 PhD-granting institution in New York with a diverse and international student body.⁵ Intermediate Microeconomic Theory at Institution A is a calculus-based course that includes topics ranging from consumer preferences and utility to uncertainty and risk, behavior of firms, monopoly, and price discrimination.

The course is required for economics majors, though it also draws some students from outside the major who want to gain a deeper understanding of the economic aspects of individual and firm decision-making. The skills taught in the course are broadly applicable to more advanced economic courses, and the course can also serve as a technical elective for some majors.⁶ Few first-year students take the course, as principles of microeconomics and introductory calculus are prerequisites, with students often opting to take principles of macroeconomics before enrolling in any intermediate-level courses.

The enrollment in the class ranges from 80 to 150 students depending on the semester, and in Fall 2022, 137 students (in one

⁴ [Roschelle et al. \(2010\)](#), p. 874.

⁵ 33.6 % of the class of 2024 were from the New York area, and 10.2 % were international students.

⁶ Note that students must choose a major by the end of their sophomore year, and they can declare the economics major after completing Introductory Microeconomics, Introductory Macroeconomics, and a prerequisite math course (all of which can also be satisfied by AP credit). Most students at Institution A declare a major during or towards the end of their fourth semester.

section) completed the course. Teaching during this semester was not significantly affected by the COVID-19 pandemic. All lectures were held in person and students were free to work in groups without restrictions. Students taking the class came from both publicly supported and privately funded schools within the university.

In Fall 2022 we introduced new interactive exercises into the work that students did outside class time. These graded problem sets accounted for 20 % of students' end-of-term course grades. The problem sets also included traditional pencil and paper exercises. Students completed 6 problem sets during the term, and each contained at least two of our new interactive exercises. Most exercises start by asking the students to guess the answer based on their intuition. Then the student is instructed to use the graph to test their hypothesis (and encouraged to go above and beyond, perhaps creating a more generalized solution by playing with the graphs), before finally confirming the result with algebra. An example exercise is included in Appendix A.1

2.2. Institution B

Institution B is a statutory R1 PhD-granting institution in California with a diverse and international student body. We used the exercises in two classes at this institution, Economic Analysis I ("Class 1") and Economic Analysis II ("Class 2"). Class 1 is a multi-variable calculus-based course that includes topics on consumer and producer optimization, comparative statics, and partial equilibrium. Class 2 is a course that builds on Class 1 and explores topics of game theory, imperfect competition, risk and uncertainty, intertemporal consumption, and general equilibrium. Both courses are required for Economics majors and minors; there are no alternatives with less rigorous mathematics requirements. Additionally, Class 1 is required for the economics track in a number of other majors.

The enrollment in the classes ranges from about 60–150 students per quarter. In Fall 2022, there were 116 students in Class 1, and 103 in Class 2. As at Institution A, teaching was not particularly impacted by the COVID-19 pandemic, and classes were held in person.

Unlike Institution A, the interactive exercises at Institution B were assigned as part of online pre-class quizzes based on the reading. The purpose of these quizzes was threefold:

- to incentivize the students to do the reading before coming to class;
- to familiarize the students with the visual representations they will be seeing in lecture; and
- to alert them to common misunderstandings that they may have formed during the readings.

To serve these purposes, several types of exercises were developed:

- Check your understanding (CYU) exercises were low-stakes tasks which students could perform and get immediate feedback. For example, in the preclass quiz on budget sets for Class 1, one exercise asked students to draw the budget set for a consumer with \$16 who could buy apples for \$2 per pound and bananas for \$4 per pound. The student were instructed to drag the endpoints of the budget line to the bundles corresponding to all \$16 being spent on apples, or bananas; they were then asked to place three points so that they lay within, along, or outside of the consumer's budget set. They could then check a "reveal answers" box which provided feedback as to which aspects of the task they had done correctly.
- Illustrative questions were tasks that were intended to help walk a student through a concept from the reading. For example, in Class 2, students used an interactive visualization of a Cournot model, which showed the firms' profits, to compute the best response to various choices made by the other firm. They entered their results in a graded Canvas quiz. Then, in class, the more formal theory of best response functions was developed using calculus, building on the intuition that they had gained in the pre-class quiz.
- Puzzle questions were more difficult questions geared at understanding cause and effect. In these questions, students were presented with a diagram that did not provide full information, and asked to draw conclusions based on the relationships described in the reading. For example, in a quiz on complements and substitutes, students were presented a graph in which they could change the price of one good and see the effect on the demand for another good. They were then asked to determine whether the goods were complements or substitutes, based on the observed behavior of the graphs. They entered their answers in a Canvas quiz, and were graded on those answers. To prevent cheating, multiple versions of the question were created, so each student's graph behaved differently. Students were informed of this.

Examples of the exercises are included in Appendix A.2.

2.3. Institution C

Institution C is a highly-ranked public PhD-granting research-intensive university in the United Kingdom with a diverse and international student body. Mathematics A levels are required for admission into the Economics or Economics and Finance degree

programs in which Intermediate Microeconomics is a compulsory course split over two terms.⁷ The interactive graphs were used in the second half of the course. This part of the course focuses on strategic interactions and game theory, with applications related to information economics, the economics of incomplete contracts, risk preferences, credit markets, and labor markets. The course uses algebra and multivariable calculus. As with Institution B, there are no alternatives with less rigorous mathematics requirements for students in these degree programs.

The enrollment in the classes ranges from about 110–500 students per year. In the academic year 2022–23, there were 482 students in Intermediate Microeconomics (split in two units (“sections” in US parlance) of the same course). Classes were held in person as with institutions A and B. The course is taught with a mixture of lectures (once per week), exercise lectures (once every two weeks), and small-group tutorials taught by tutors (once every two weeks). Interactive graphs were used in exercise lectures and in tutorials, though students could also access them through links in the e-book version of the textbook.

The main use of the interactive graphs was in the exercise lectures where they were part of structured exercises that students were expected to complete before the exercise lecture, but which many students would do during the lecture itself. As with Institutions A and B, the students would answer a question about the theory and about how the outcomes in the graph would change if parameters changed (following the structure of the SimCalc methods outlined earlier). A sample exercise lecture question is included in Appendix A.3.

Unlike in the US, UK economics departments typically do not permit the use of smallstakes quizzes or participation grades tasks for summative assessment grades (e.g., check, check plus, check minus). As a result, the exercise lectures and the tasks in tutorials that used the interactive graphs are only for formative assessment; students can do them, see the answers provided by the lecturer or tutor, and ask their lecturer or their tutor for additional feedback. In the case of one tutorial exercise (without interactive graphs), the tutorial was graded and written feedback was provided by the tutor if the student submitted the tutorial problem set, but this was voluntary and many students do not choose to submit tutorial problem sets to get feedback on them. Thus, the exercises were not part of students’ final grade of the course.

3. Feedback from students

At all three institutions, we surveyed the students at the end of the semester to learn what they thought of the interactive exercises and whether they found them useful alongside the traditional pencil and paper problems. We could not, however, administer identical surveys at each institution because of differences in the ways in which teaching occurs at the three institutions. Ethical review board clearance was obtained to get additional data at institutions A and C for further analysis to be conducted.

3.1. Institution A

Students were specifically asked two open-ended questions about the exercises they were assigned in the course:

1. In general, did you feel that the pencil and paper exercises helped you to better understand the material? If so, how?
2. In general, did you feel that the interactive visualization exercises helped you to better understand the material? If so, how?

A research assistant at Institution A read each student’s sentiments toward each type of exercise and classified responses into one of four categories. This categorization was reviewed by one of coauthors of this paper and found to be very reliable. The categories are defined below:

(Very Helpful) Students found the exercises very helpful. They either explicitly state they found them “extremely/very helpful” or they provide a fairly long and detailed positive response of the response. e.g., “The interactive visualization exercises helped me better understand the material because I was able to take the concepts that I just learned and see it put into play with the problems. I would also write down what would happen in the simulations/problems.”

(Somewhat Helpful) Students found the exercises moderately helpful. e.g., One student reported “yes, I thought they were a good way to engage with the material”

(Neutral or Less Helpful) Students reported not finding the exercises helpful. e.g., Another student stated “Not sure. I didn’t find the visualization particularly helpful, but I also tend to be a less visual person. I could see how these types of exercises would be helpful for other students, though.”

(Misunderstood Question) Some students clearly misunderstood the question. The most common misunderstanding was thinking that the question was referring to the polling questions that were asked during class time. e.g., One of our students reported “I liked seeing the poll everywhere answers and being able to pinpoint my answer on a graph and see what other people were thinking.”

Fig. 1 shows the distribution of categorized responses to the questions about each type of exercises. We omitted five students who

⁷ US Audiences should consider the UK degrees as majors with different, but similar, course completion requirements for graduation. There are also slight differences in entry qualifications and structure between degrees: unlike the US, a student in the UK is admitted to a specific degree based on their high school courses and marks for those courses. For example, the Economics degree and Economics and Mathematics degree have similar structures, with students in Economics and Mathematics taking extra mathematics courses and fewer economics electives. Economics and Finance degree students take slightly fewer economics electives and more finance courses and the entrance requirements for Economics and Finance can be marginally lower compared to straight Economics or Economics and Mathematics.

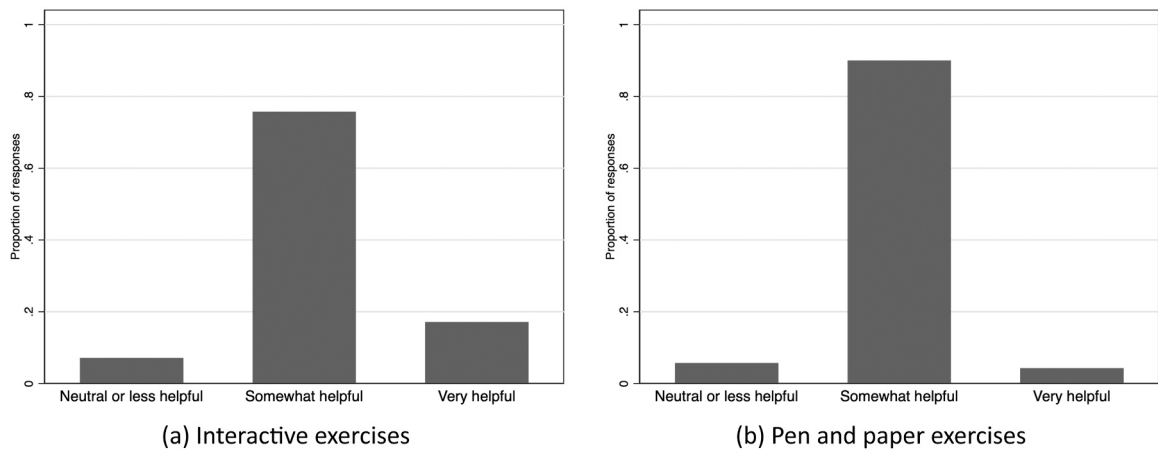


Fig. 1. The distribution of answers by students to questions about the use of interactive graphs and pencil and paper exercises in problem sets.

clearly misunderstood the question about the interactive exercises and three students who did not understand the question about the pen and paper exercises yielding samples of 81 and 82 students. 93 % of students found the interactive exercises at least somewhat helpful while 94 % found the pencil and paper exercises at least somewhat helpful. At the same time, 17 % of students found the interactive exercises very helpful while only 4 % of the students found the pencil and paper exercises very helpful.

3.2. Institution B

Data was collected as part of the standard course evaluation process at the end of the term. Students are not required to fill out course evaluations, but they gain early access to their grades if they do so. However, students did not always complete all the questions and thus a student may have started the survey, but their data may be missing for given questions. For the questions under investigating, we only include students in the sample who completed all three questions. In Class 1, 106 out of 116 students completed the survey, but only 93 answered all of the questions, for an effective response rate of 80 %. In Class 2, 85 out of 103 students completed the survey, but only 74 answered all of the questions, for an effective response rate of just under 72 %.

Unfortunately, the instructor at Institution B was not able to obtain demographic data, because they are not included in the course evaluation reports and it was not possible to get ethics clearance to obtain this data. As a result, we were not able to conduct regression analysis to determine whether the exercises were particularly useful to certain types of students. We summarize the responses to the survey data below.

First, students were asked the following open-ended questions about pre-lecture quizzes. The first question asked how useful the quizzes were in general; the second asked about the questions that used interactivity in particular:

1. In general, did you feel that the pre-lecture quiz questions (both interactive and noninteractive) helped you to come to class better prepared? If so, how?

About 70 % of the responses to this question were positive. The most positive one said "I thought the pre-class quizzes allowed me to be more prepared for class and get a better understanding of the material in class because it was the second time seeing it. I liked the interactive ones with the graphs because I liked how you could visually see the changes." Most of the positive responses mentioned that they incentivized students to do the reading.

About 15 % of the responses were negative. Several of these mentioned stress caused to students: for example, one wrote "They helped with organizing the way to process the readings, but they were very stressful and as someone who has difficulty [sic] learning from a textbook it felt somewhat unfair to be tested on the material before class." Interestingly, that same student wrote in response to the next question: "I thought that the ones with interactive visualized questions were particularly helpful, the reading/written ones seemed less helpful as it was harder to process than during the in class explanation." This provides some preliminary evidence that providing a guided interactive introduction to the material may help to alleviate student stress, which is a possibility worth investigating further.

Finally, about 15 % were neutral. Most of these said the questions were useful but tedious, or that they basically just searched the text for the questions so that the quiz didn't achieve its goal of having them absorb the material.

2. In general, did you feel that pre-lecture quiz questions which used interactive visualization helped you to come to class better prepared? If so, how?

The responses to this question were even more positive than the first question: of 144 students who answered this question, 118 (82 %) were positive, 16 (11 %) were negative, and 10 (7 %) were neutral. One student in Class 1 wrote "Yes! It's super helpful to see it change in real time, rather than trying to juggle all the concepts mentally. Made this so much more enjoyable than Econ 1." Another wrote "Yes, because I was able to see how the graphs shifted and moved and then in class we learned why which was helpful." In Class 2, one student wrote "Yes, a lot of the theory behind some of the things we learn are very confusing and I really only gain grasp of the thing once I visually see it." Another wrote: "Those helped me a LOT and I would really like to have more of them! When I see a static

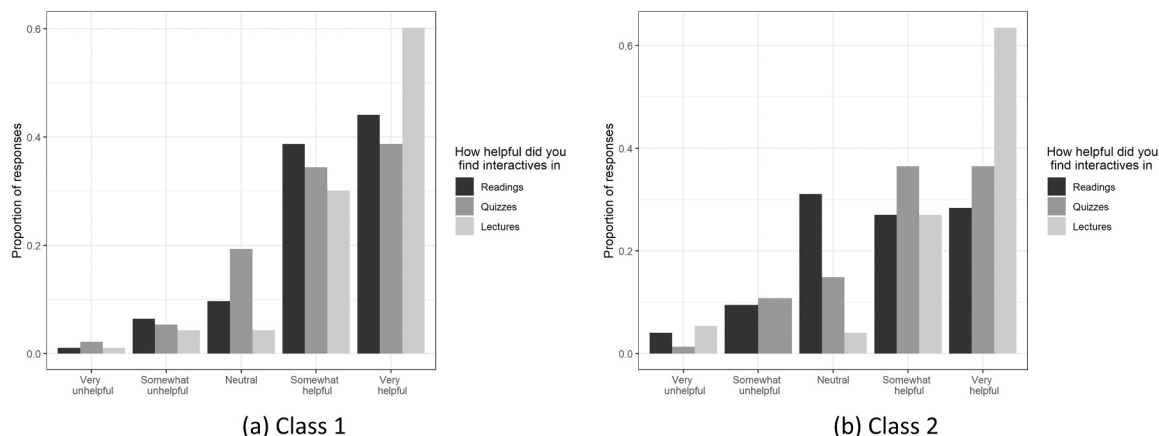


Fig. 2. The distribution of answers by students to questions about the use of interactive graphs in Class 1 and Class 2.

diagram or a bunch of math equations in Varian I'm usually thinking like 'ok, I'll just accept this at face value.' But when I get to play around with the sliders and see how the graphs change, I start to truly believe that 'oh, setting the price/quantity at this level does indeed make everyone better off!'"

Of the 16 negative comments, only three said the interactive questions themselves were worse than the non-interactive questions; the others were largely negative on the whole concept of pre-lecture quizzes.

The 10 neutral comments were typified by the student who said "I felt that interactive and non-interactive were equally helpful." We categorized these as "neutral" rather than "positive" because we were using this question to measure the *difference* between interactive and non-interactive questions.

There were almost no negative comments; most of the few that weren't positive were just neutral, saying that the interactive questions were no better or worse than the ones based on the reading.

The second pair of questions dealt with a broader range of content types. At this institution, students are given three kinds of exercises: pre-lecture quizzes, homework exercises based on the lectures, and old exam questions to give them an idea of the structure of the questions on the midterm and final. Furthermore, beyond their use in exercises, interactive graphs from econgraphs.org are used in as part of an interactive textbook and in lecture itself. (The interactive textbook had comprehensive coverage for Class 1, and covered about 25 % of the material in Class 2.) The last two questions the Instructor asked the students tried to get at the relative usefulness of interactivity in these different contexts: 3. *Was there any exercise (in a quiz or homework) that you thought was really valuable?*

If so, tell us why you found it useful.

Most of the students said that the old exam questions were the most useful, because they helped them study for the exams. Very few mentioned the interactive quiz questions.

In conjunction with the results on the quiz questions above, this suggests that students recognize that different types of exercises serve different purposes. From their perspective, because the majority of their grade depends on the exams, it makes sense that the most useful type of exercise is those which are most closely aligned with the exam; and since exams are given without any interactivity, students perceive (rightly or wrongly) that the interactive questions are less useful in preparing for exams.

This is consistent with other uses of interactive content, which focuses more on *formative assessment* rather than *summative assessment*. The scaffolded nature of the interactive exercises used in this project was explicitly intended to help students gain an initial intuition of what's going on in economic models.

4. More broadly, interactive graphs were used in readings, in quizzes, and in lectures. How helpful did you find each in understanding the material?

In each class, the students responded positively to the use of interactive graphs in quizzes, with 74 % of Class 1 and 72 % of Class 2 saying they were "very" or "somewhat" helpful.

The students responded the most positively to the use of interactive graphs in lectures, with 90 % of the students in each class rating them "very" or "somewhat" helpful. This may be because the interactive graphs have been integrated into nearly all of the lectures in both of these classes for several years, whereas only a few of the quizzes contained interactive exercises as part of this pilot project.

In prior years, when the graphs were *only* used in lectures, some student evaluations had complained about getting lost by what was going on in lecture when the instructor manipulated the graphs. This suggests that giving the students an opportunity to play with the graphs before lecture, either as part of a pre-lecture quiz or in the textbook reading, is *complementary* to using the graphs in lecture.

Fig. 2 summarizes the results of the last question.

3.3. Institution C

Institution C does not conduct student evaluations of teaching (SETs) that permit adding additional instructor-specific or course-

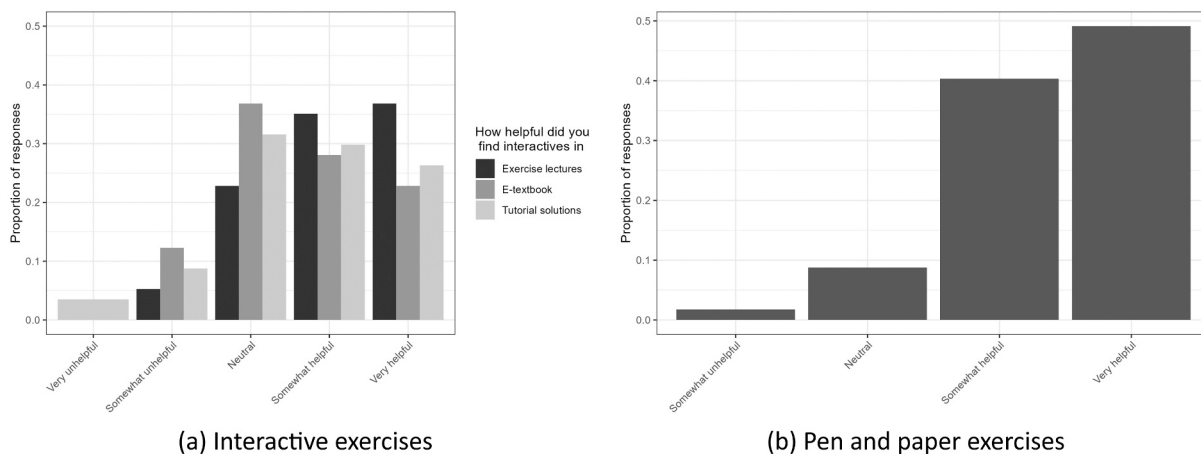


Fig. 3. The distribution of answers by students to questions about the use of interactive graphs and pen and paper exercises.

specific questions around teaching innovations. Instead, we obtained ethics clearance to administer an incentivized in-class survey. Students who completed the survey were given the opportunity to win an Amazon voucher worth 20 GBP (there were 20 such vouchers). The survey was conducted at two points in the term to try to permit students more time to answer the questions. The response rate was nonetheless low, with only 75 students of the 482 responding to the survey and only 57 of those having completed the surveys for all relevant questions (around 12 % of all the students registered for the class). We use 56 of these observations because one student did not sit for the final exam.⁸

At Institution C we report the results of 3 questions similar to those at Institution B, though different because of the slightly different teaching methods in the UK. These questions are "How helpful did you find the interactive graphs in [teaching mode]?" where the teaching modes include the exercise lectures, the e-textbook, and the tutorial solutions (the instructor can control the tutorial solutions, but this does not mean a given tutor will use the interactive in the tutorial session itself, which is why the question is worded this way). We also ask how useful students find straight pen and paper exercises with the vast majority of them reporting that these exercises were helpful. Fig. 3 provides the results of these questions. The comments that students made suggest that students find the pen and paper exercises and interactive exercises to be *complements* rather than substitutes, that is, that pen and paper exercises perform one function and that the interactive graphs perform another and that the two together provide a helpful mode of learning that each one by itself may struggle to achieve.

Compared to the US institutions, a greater proportion of students in the UK report that they feel "neutral" on whether the interactive graphs are helpful, though a significant proportion also reports that they are "somewhat helpful" and "very helpful" in all three modes. A small proportion of students reports that the interactive graphs are "very unhelpful" in tutorial solutions. One of the two students who said the interactive graphs were "very unhelpful" commented that, "[Interactive graphs] can sometimes be useful in visualising shifts, but I find it easier to understand by looking at equations and seeing how a variable changing will affect curve." So it is important not to over-interpret the student's comment as saying that the interactive graphs are *not useful to other students*, rather this student's claim is that they prefer the mathematical depiction of functions and seeing how variables change in the function (e.g., in one exercise students both take the derivatives with respect to each policy variable as well as seeing how those variables shifts the curve in the interactive; some students unequivocally prefer just doing the mathematics). This answer is similar to another student who answered "neutral" and said, "I tend to understand the equations of the curves, I don't find the interactive graphs very useful."

Many student comments endorse the idea that the interactive figures are (somewhat or very) helpful in a variety of different applications.

- "They are all helpful and really aid my understanding of the models."
- "The interactive graphs work really well and are really helpful in understanding the effects of specific variables."
- "Allow deeper insight into graphs and encourages greater understanding."

In particular, students found the interactive graphs helpful where things were difficult to understand from the equations for the relevant figures, where many parameters could affect different outcomes, and where learning activities were structured so that students would answer many questions about the same graph, typically combining mathematical and graphical questions.

- "The exercises where lots of questions were asked on one graph helped get a large overview and understanding on each line and interpretation of the graph."

⁸ A student therefore had approximately a 20/57 chance of getting a 20 GBP voucher.

Table 1
Summary Statistics at Institution A.

| Variable Name | Percentage |
|------------------------------------|------------|
| Female | 43.66 |
| Underrepresented Minority (URM) | 8.45 |
| Economic Events in Day-to-Day Life | 84.51 |
| Economics is Interesting | 91.55 |
| Liked Interactive Exercises | 92.96Count |
| Observations | 71 |

- "The labour market example was really helpful - there were a number of factors which all affected the model in different ways and so it was good to visualise how each variable affects the curves/outcomes."

Some students report that the interactive graphs are more appropriate in some teaching modes rather than others, for example: "I find it more useful in seminars [small-group classes of 15–30] rather than exercise lectures." At Institution C, exercise lectures are large venue classes with many students in them and students report that they don't understand the interactive graphs as easily when they are used in the large lectures. It may be the case that student attention may be more focused in smaller classes where there may be fewer distractions compared to larger lectures where they may be more easily distracted by fellow students, their devices, and where they may be multi-tasking rather than focusing on the content.

4. Multivariate analysis of feedback

4.1. Institution A

In addition to answering survey questions about the interactive exercises at the end of the term, students at Institution A took two standard assessments of their prerequisite skills at the beginning of the term. At the same time, they also provided demographic information and answered two questions about their initial attitudes toward economics.

For the purposes of our analysis, we created a binary measure for whether students had a positive impression of the interactive exercises based on the categories defined in 3.1 above. The measure was defined to be one if the student considered the exercises "Very Helpful" or "Somewhat Helpful" and zero if they considered them "Neutral or Less Helpful." If a student did not provide any answer or misunderstood the question, we did not include them in the analysis.

While we were curious about how much students valued the exercises, we also wanted to know if some students valued them more than others. In particular, we wanted to know if the exercises helped the less-prepared students by providing graphical intuition before having them work with equations and if there were certain demographic groups getting more out of the exercises than others.

The standard assessments that we gave to students at the beginning of the term were the intermediate-level Mathematics for Economics Skills Assessment (MESA-Intermediate) and the Principles of Economics Assessment for Microeconomics (PESA-Micro). MESAIntermediate is a multiple-choice assessment comprised of 31 questions designed to test the mathematical skills required for success in intermediate-level economics courses, and PESAMicro is a multiple-choice assessment comprised of 30 questions designed to test the learning goals of a typical introductory course in microeconomics. We standardize the scores to have a mean of zero and variance of one before incorporating them into our regression models.

Alongside the beginning-of-term assessments, students were asked about their demographic characteristics (including gender, race, parental education, and parental occupation), as well as their attitudes towards economics. In our analysis we focus on the roles of gender⁹ and underrepresented minority group (URM) status. We define a student to be from an underrepresented minority group if they at least partially identify as Black, Hispanic, American Indian, or Native Hawaiian/Other Pacific Islander.

Students are asked for their level of agreement with two statements about their attitude toward economics:

1. "I think about economic events I experience and witness in day to day life (e.g., in your own life and decisions, on the news, internet articles, etc.)"
2. "I think economics is interesting and applicable for people like me."

Students report their agreement on a five-point scale: (1) for Strongly Agree, (2) for Somewhat Agree, (3) for Neither Agree or Disagree, (4) for Somewhat Disagree, and (5) for Strongly Disagree. We created a dummy variable for each of these questions that is one if the student strongly or somewhat agrees and is zero otherwise.

137 students completed the Intermediate Microeconomic Theory course in the Fall 2022 term. Of these students, 113 students responded to the survey. We removed 27 students from the sample who left the question about the value of the interactive exercises blank, and we removed another 8 students because they clearly misunderstood one of the questions. 71 of the remaining 81 students

⁹ Students chose their gender from four categories: Male, Female, Prefer to self-describe, and Prefer not to say. All students in our sample chose either Male or Female.

Table 2
Effects of student characteristics on attitude toward interactive exercises at Institution A.

| | (1) | (2) | (3) | (4) | (5) |
|------------------------------------|--------------|--------------|--------------|--------------|--------------|
| Female | -0.05(0.06) | -0.06(0.06) | -0.07(0.07) | -0.06(0.06) | -0.07(0.06) |
| Underrepresented Minority (URM) | 0.08*(0.04) | 0.07+(0.04) | 0.04(0.03) | 0.06(0.04) | 0.02(0.05) |
| MESA-Intermediate (standardized) | | -0.06*(0.03) | | -0.04(0.03) | -0.04(0.03) |
| PESA-Micro (standardized) | | | -0.06*(0.03) | -0.02(0.03) | -0.03(0.04) |
| Economic Events in Day-to-Day Life | | | | | 0.17(0.14) |
| Economics is Interesting | | | | | -0.07(0.07) |
| Constant | 0.94**(0.04) | 0.95**(0.04) | 0.96**(0.03) | 0.95**(0.03) | 0.88**(0.10) |
| Observations | 71 | 71 | 71 | 71 | 71 |
| R ² | 0.016 | 0.070 | 0.059 | 0.074 | 0.124 |

Robust standard errors in parentheses.

Note: The dependent variable is a dummy that takes the value one if the student expressed a positive attitude toward the interactive exercises and is zero otherwise.

* $p < 0.05$

** $p < 0.01$

+ $p < 0.1$

Table 3
Summary Statistics for Institution C.

| Variable Name | Percentage |
|--|------------|
| Female | 25 |
| Home students | 83.93 |
| Micro grade classification ($\geq 60\%$) | 78.57 |
| BSc Economics | 71.43 |
| BSc Economics and Finance | 16.07 |
| BSc Economics and Mathematics | 5.36 |
| BSc Economics and Econometrics | 3.57 |
| MSci Economics with Innovation | 3.57 |
| Economic Events in Day-to-Day Life | 80.36 |
| Economics is Interesting | 78.57 |
| Liked Interactives (in general) | 64.29 |
| Liked Interactives in Exercise Lectures | 71.43Count |
| Observations | 56 |

took the two prerequisite skills assessments and self-reported their gender, URM status, and attitudes toward economics.

Table 1 shows summary statistics for the analysis sample. It is reassuring to see that most students enter the course believing that economics is interesting and thinking about economic events in their day-to-day lives. We were also happy to see that almost 93 % of the sample reported finding the interactive exercises moderately or very helpful.

In Table 2 we report the results of estimating a series of linear probability models. The dependent variable has a value of one if a student found the interactive exercises moderately or very helpful. While our relatively small sample size does not give us a lot of statistical power, a few results emerge. First, we find that students with URM status are significantly more likely to have a positive attitude toward the interactive exercises in specification (1). However, once we control for pre-existing skills in (4) and (5), neither gender nor URM status have statistically significant relationships with students' attitudes toward the interactive exercises.

Second, the assessments of prerequisite skills are significant predictors, and students who score lower on these tests are more likely to appreciate the interactive exercises. Because these scores are highly correlated ($r=0.68$), the coefficients lose individual significance when both are included in the same model as they are in (4) and (5). However, in both of these models, the coefficients are jointly marginally significant with a p-value of 0.08.

Third, we see no significant effect of attitudes toward economics on attitudes toward the interactive exercises in (6), though the standard errors on these coefficient estimates are large. These coefficients are neither individually significant nor jointly significant.

4.2. Institution C

At Institution C students answered the same questions about their attitudes toward economics as were posed at Institution A, though the timing differed. These questions were included in the same survey as the questions about the interactives that was fielded during the second half of the academic term. We also collected and merged some administrative data, like personal characteristics and their final grade in the Intermediate Microeconomics course.¹⁰ Personal characteristics include sex, fee status (home vs. international students), and their degree specification. We coded students' grades in the different classifications of the UK academic system (fail to

¹⁰ Ethics approval has been granted by the School of Economics Research Ethics Committee (SEREC) at Institution C.

Table 4
Effects of student characteristics on attitude toward interactive exercises in exercise lectures at Institution C.

| | (1) | (2) | (3) | (4) | (5) |
|------------------------------------|---------------|---------------|--------------|--------------|--------------|
| Female | 0.20*(0.10) | 0.20*(0.10) | 0.18(0.11) | 0.18(0.11) | 0.17(0.11) |
| Home students | 0.15(0.17) | 0.13(0.17) | 0.19(0.19) | 0.24(0.17) | 0.24(0.18) |
| EconFinance | 0.22(0.15) | 0.24(0.15) | 0.30**(0.14) | 0.27*(0.14) | 0.28**(0.14) |
| High Micro Grade | | -0.09(0.15) | -0.03(0.14) | -0.09(0.13) | -0.07(0.13) |
| Economic Events in Day-to-Day Life | | | 0.36**(0.17) | | 0.15(0.21) |
| Economics is Interesting | | | | 0.41**(0.16) | 0.32(0.19) |
| Constant | 0.51***(0.17) | 0.59***(0.22) | 0.20(0.29) | 0.17(0.25) | 0.10(0.27) |
| Observations | 56 | 56 | 56 | 56 | 56 |
| R ² | 0.07 | 0.08 | 0.17 | 0.21 | 0.22 |

Robust standard errors in parentheses.

Note: The dependent variable is a dummy that takes the value 1 if the answer to the question "Interactive graphs are used in exercise lectures. How helpful do you find them in understanding the material?" was "somewhat helpful" or "very helpful" and 0 otherwise.

- * $p < 0.1$
- ** $p < 0.05$
- *** $p < 0.01$

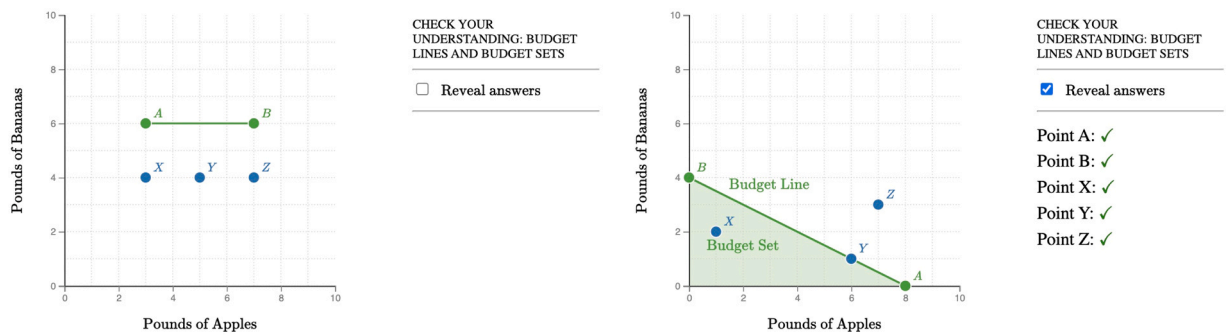


Fig. 4. Check Your Understanding Question A.2.1, (a) Exercise Presented to Student (b) Correctly Completed Exercise.

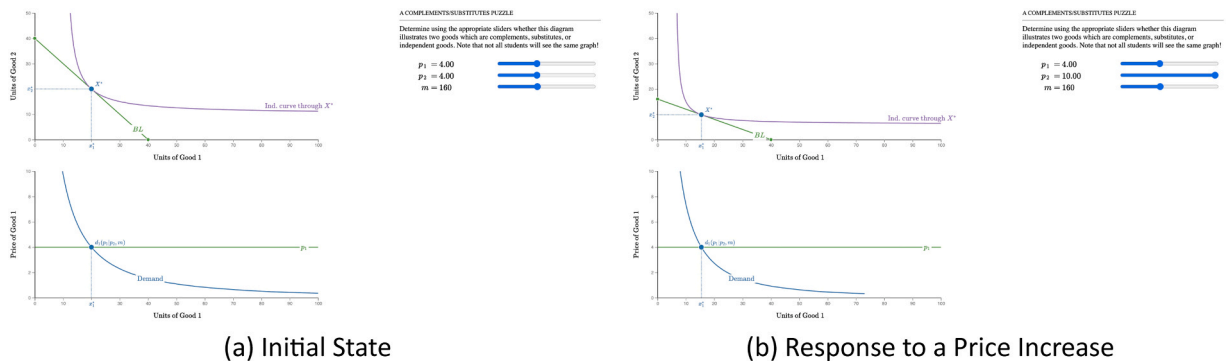


Fig. 5. Puzzle Question A.2.2.

first class).¹¹ The degree specification variable (EconFinance) is a dummy variable that takes the value 1 if the student is registered in BSc Economics and Finance and 0 otherwise.

Table 3 provides the relevant summary statistics for the variables that have been used in our regression analysis. The majority of the respondents are male, home students, who scored a high grade in the course.¹² Most of them pursue a BSc in Economics degree and they find economics interesting and relevant to Day-to-Day life. The dummy variables “Economic Events in Day-to-Day Life” and

¹¹ For international comparisons, a first class is roughly equivalent to an A.

¹² By high grade we mean students who achieved an Upper Second-Class Honours in the class or above. For context, the UK degrees are classified as follows: First-Class Honours (70 % and above), Upper Second-Class Honours (60–70 %), Lower Second-Class Honours (50–60 %), and Third-Class Honours (40–50 %).

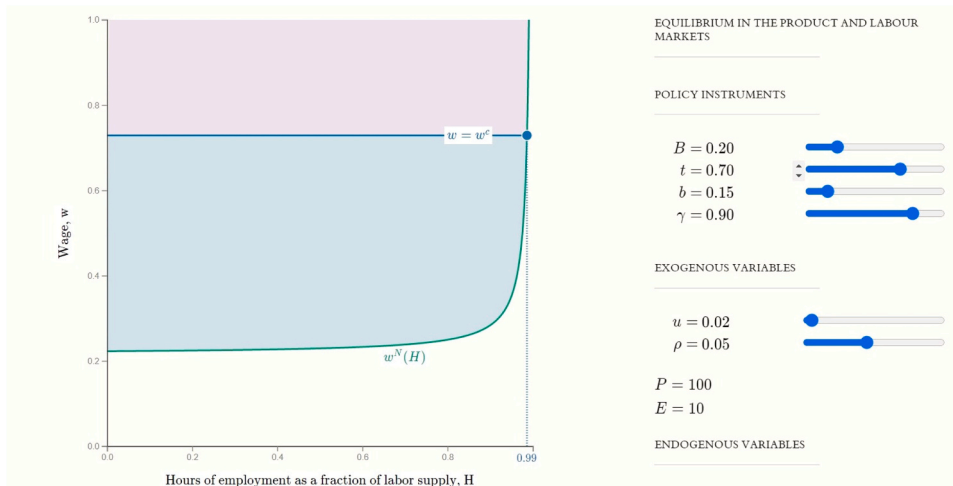


Fig. 6. Example interactive graph

“Economics is Interesting” take the value of 1 when students’ answer in the respective questions is “Agree” or “Strongly agree” and 0 otherwise. Around 71 % of the students find the interactive graphs useful when used in exercise lectures, while the average is a bit lower if we include all the three teaching modes (exercise lectures, etextbook, and tutorial solutions). The variable “Liked Interactives in Exercise Lectures” takes the value 1 if the answer was “somewhat helpful” or “very helpful” and 0 otherwise. Though the interactive graphs were available in tutorial solutions and the e-textbook, the instructor used them specifically in exercise lectures, which is why we emphasize the role of this specification. The variable “Liked Interactives (in general)” takes the value 1 if students have responded with “somewhat helpful” or “very helpful” in two out of the three questions on interactives, and 0 otherwise.

In Table 4 we report the results of a series of linear probability models on students liking the interactive graphs in exercise lectures. We run five different specifications and include the relevant controls.¹³ In the first two specifications we see a mild correlation between being a female (as reported in administrative data) and liking the interactive exercises more, however the coefficient does not remain statistically significant once we control for students’ attitudes towards economics. We see that students who think that economics is interesting or who think about economic events in their day-to-day life seem to find the interactive graphs more helpful. Even though the coefficients lose individual significance when both are included in the same model (specification (5)) due to high correlation ($r=0.62$), they are jointly significant with a p-value of 0.03. We also see a correlation with students’ degree specification, where students enrolled in an Economics and Finance degree seem to respond more positively about the interactive graphs.¹⁴ Finally, we do not observe any statistically significant effect of students’ status and grade classification on attitudes toward the interactive exercises.

5. Discussion

The results suggest that students find that working through exercises that use interactive graphs is helpful, and that students who enter the course less technically prepared in particular find the interactive graphs valuable. We also find some evidence that students that are more intrinsically motivated to study economics appreciate the value of the exercises more than other students.

This initial work is intended to be part of a broader project that studies how the use of interactive graphing and problem-solving can be used in economics alongside other practices informed by the learning sciences (such as spaced repetition and interleaving) to improve student learning outcomes. We also plan to investigate the potentially significant impact of these kinds of exercises on student mindset and belonging.¹⁵ Our project is currently focused on intermediate microeconomics, a core course for economics majors (US) or students in an economics-focused degree program (UK). Given our results, producing interactive graphs for courses in which students do not have the same mathematical preparation as is typically expected of a student in microeconomic theory (e.g., advanced algebra and calculus), may be particularly useful for student learning, student understanding of the policy implications of models and modeling assumptions, and other important student outcomes (Girardi et al., 2024; Espín et al., 2022).

This pilot study at three sites also provides lessons for thinking about multi-site work both within the same country and across

¹³ In all specifications one observation is dropped from the sample, as the student deferred their exam and their grade is missing. Also, 8 students answered the survey in two different points in the term. For clarity and because we do not have enough observations for a panel dataset, we keep only their answers in the first point.

¹⁴ Given the different degree structures and requirements discussed earlier in Footnote 7, Economics and Finance students might like the interactive graphs more and find them more helpful either because of different levels of entering preparation or because of different courses that they take during the degree program.

¹⁵ For recent work on a belonging intervention in a multi-site context see Walton et al. (2023).

countries. With institutions that differ in administrative rules and expectations around faculty roles, as well as with expectations around scholarship on education, the kinds of data and the procedures to be followed to get data are very institution-specific and inconsistent across sites. Furthermore, differences in content, standards around prerequisite courses, the structure of how courses are taught, and other institutional differences means that even when similar interventions are adopted, the ways in which they can be implemented may differ substantially and thus the ways in which students can be surveyed and evaluated about their impact will differ.

One way to estimate the causal effect of these exercises on student learning would be to run a randomized controlled trial. This would be a significant undertaking, and if we wanted precise estimates of effects for subgroups such as URM students, we would need a substantially larger sample of classes and students than is usually found in economic education studies because URM students are generally a small proportion of students in any given class (URM students are approximately 14 % of majors nationally in the US by one estimate (Bayer et al., 2020b)).

Notwithstanding these challenges, our paper provides insights into the ways in which students find interactive graphs helpful for their learning in intermediate microeconomics, establishes a basis on which to engage in future research with open-source software for interactive graphs in other courses and in combination with other interventions, and provides insights into the kinds of challenges economics education researchers will need to overcome to make this kind of research more robust in the future.

Data availability

We are happy to make the code accessible as a Github page or as a separate document upon acceptance

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Appendix

A Examples of exercises

A.1. Institution A: Example Exercise

The exercise starts by asking students to consider a duopoly where each firm had the following demand and cost functions:

$$Q = 14 - p(1)$$

$$C(q) = 2q(2)$$

Above the questions in the exercise, the interactive is displayed, and in the Cournot Duopoly exercise, three graphs are shown. The first two graphs plot each firm's residual demand given the market demand and the other firm's choice of quantity. Each graph also demonstrates the profit earned from a certain quantity produced. Adjusting the quantity produced in one firm's graph also adjusts in the other firm's graph and the third graph, which shows the market demand curve for the good and the total amount produced by both firms. Each firm's graph has the ability to show the marginal revenue, and the market demand graph has the option to show individual firm quantities in the aggregate market. Then, students are asked questions (a) through (h):

- (a) Suppose Firm 2 exits the market. Model this in the graph by moving this firm's choice of quantity to 0. Use the graph to determine the profit-maximizing quantity that the Firm 1 (now a monopoly) produces and the profit they earn. That is, drag their choice of quantity until profit is as high as you can make it. Verify this result using algebra.
- (b) Now consider a market where the firms need to account not only for their own output, but also how much the other firm produces. If Firm 1 knows that Firm 2 will produce two units of output, how much should Firm 1 produce to maximize their profit? Use the graph to determine your answer, then verify using algebra.
- (c) Suppose that Firm 2 now reacts to Firm 1 setting their level of output to the above quantity. What is the optimal output for Firm 2 given that Firm 1 produces the amount in (b)? Use the graph to determine your answer, then verify using algebra.
- (d) Continue this back-and-forth process a few more times using the graph. What outcome does it converge to? That is, at what quantities are both firms optimally responding to what the other firm is doing? What is the price, and the total profit?
- (e) Starting with each firm's profit maximization problem, algebraically demonstrate why the quantities you found in (d) are the optimal levels of output for each firm given that they know each other's best response functions.
- (f) A Nash equilibrium is a situation where a unilateral deviation by a single agent is not beneficial for that agent. Briefly explain why this scenario is a Nash equilibrium.
- (g) Use the graph to determine whether there is a combined level of output where both firms make more profit than they do in the Cournot equilibrium. What quantity did you find? Now algebraically determine the optimal level of total output. How does this compare with the optimal level of output you calculated for Firm 1 in (a) when they did not have to compete with Firm 2?

(h) Explain why the situation in (g) is NOT a Nash equilibrium.

Each part of the exercise builds on work done earlier. Parts (a), (b), (c), (d), and (g) all explicitly require the model visualization to solve the exercise, although the interactive could be used to solve in other parts of the question as well. The students then algebraically confirm their graphical answers and conclude that the Cournot equilibrium choice of each firm is to sell 4 units at a price of 6 per unit. The individual profit for each firm is 16. Students also use the interactives to do simple calculations; for example in part (b), students can first adjust the slider in Firm 2's graph to a quantity of 2. Then, students can move the slider in Firm 1's graph to determine that Firm 1 will produce a quantity of 5 because that is where marginal revenue equals marginal cost. The models are also used to develop greater intuition about the solution; for example, in (f), students examine the Nash equilibrium by observing what happens to the payoffs of each firm if one of them decides to deviate from the equilibrium quantities. The interactives demonstrate that if one firm deviates, that firm's payoff will decrease. That is, students see visually that any firm's deviation from the Cournot equilibrium reduces its profits and is therefore undesirable. In (e) students use the algebra to confirm what they learned while working with the interactive.

A.2. Institution B: example exercises

A.2.1. Check your understanding question

The following exercise was intended as an easy, low-cost way for a student to check their understanding of the geometry of the budget line. It gave automatic feedback and was not graded; they simply had to check a box in a Canvas quiz saying that they had completed the exercise. See Fig. 4 for the graph presented to the student, as well as a correctly completed graph. The green check marks show up as red X's for any items placed incorrectly.

Suppose you have $m = 16$ dollars to spend on apples (good 1) and bananas (good 2).

Apples cost $p_1 = 2$ dollars per pound, and bananas cost $p_2 = 4$ dollars per pound. In the graph below:

- Draw your budget line by moving point A to the bundle that represents spending all your money on apples, and point B to the bundle that represents spending all your money on bananas.
- Move point X to a bundle that lies in the *interior of your budget set*: that is, which you can afford to buy given your income and the prices you face, and would give you some money left over.
- Move point Y to a bundle that is *along the budget line*: that is, which you can just barely afford to buy, but would leave you no money left over.
- Move point Z to a bundle that is *outside your budget set*: that is, which you couldn't afford to buy.

Once you're done, click the "reveal answers" box to see if you've got this down!:)

A.2.2. Puzzle Question

This was an auto-graded multiple-choice question delivered via Canvas. It presented a student with an interactive, and asked them to determine the underlying model based on the behavior of the diagram.

Fig. 5 shows the graph shown to the students, with sliders to adjust p_1 , p_2 , and m . Since the diagram shows the demand for good 1, the logical choice is to change p_2 and see how the demand curve shifts. However, it would also be possible to discern just from the movement of the optimal bundle in the indifference curve/budget line diagram.

All versions of the question began with the image on the left. The image on the right shows what would have happened if p_2 was increased and the goods were complements. Similar versions were created for substitutes and independent goods.

This graph shows the optimal bundle for a consumer with a particular utility function, given the prices of two goods and their income. In the top graph, it shows the budget line/indifference curve diagram; in the bottom graph, it shows the demand curve for good 1, given the price of good 2 and income. Note: different students will have graphs which behave differently!

Play around with the graph a bit, to see what happens when you adjust the prices of each good and the income.

Are the two goods pictured in this graph complements, substitutes, independent goods, or can you not tell?

A.3. Institution C: example exercise

This is an example exercise used in one of the exercise lectures during the semester. The goal was to build students' understanding of the labour and product markets. In the first three questions (a., b., and c.) students had to use the graph, describe it, and explain the intuition. Then, students had to use the intuition from the graph and construct a logic proof and also show how to find algebraically one of the curves on the graph. After that, the rest of the questions focus mainly on comparative statics with and without specific parametrization. This intended to allow students to work with the graph and identify which variables affect the curves and why. Also, by using specific parametrization, students were able to see how they can use the general algebraic formulas they found to connect them back to the graph and explain the intuition of these changes.

Consider the labour market model, where workers can exert two discrete levels of effort, e and 0. The equilibrium (no-shirking) wage in this case is given by the following wage curve:

$$w^N = B + \underline{u} + \frac{1-t}{tj} \underline{u}$$

where B denotes the unemployment benefit, \underline{u} the disutility of effort, t the probability of contract termination, and j the unemployment rate. Now, consider also the model of product markets, where firms face b barriers to enter the market. Remember that a firm's expected profits are given by the following expression:

$$\pi^E = -b(1 + \rho)w^N\alpha_l + (1 - b)(p - (1 + \rho)w^N\alpha_l)$$

where ρ is the opportunity cost of capital, α_l is the labour input requirement for a unit of output, and p is the price of the good. (Note that w^N denotes the no-shirking (equilibrium) wage and w^r the nominal wage.)

- See the interactive figure (Fig. 6). What do the green ($w^N(H)$) and the blue (w^c) curves show? Explain.
- Why are the two areas shaded blue and purple in the interactive figure? What would happen to firms if the wage were in either of those areas? Explain.
- Consider the area below the wage curve ($w^N(H)$). Why will there be no production, if the wage were in that area?
- Explain why there will always be unemployment in the market. In other words, why $H = 1$ cannot be an equilibrium. (Hint: Think how H affects w^N . What should w^N be if $H = 1$?)
- Remember that the wage curve ($w^N(H)$) shows all the possible Nash equilibria in the labour market, but it doesn't determine which equilibrium will prevail. This is why, in order to find the equilibrium (w, H) we need to consider the competition condition. Assume that $\alpha_l = \frac{1}{\gamma}$, where γ is the productivity of labour, and write the condition that needs to hold for a firm to enter the market. Solve for the real wage $\frac{w^r}{p}$.
- Use the sliders next to the interactive figure and check which of these variables affect the wage curve ($w^N(H)$) and which the real wage (w^c). Remember to change the values of the variables one by one (ceteris paribus). Explain.
- Assume $\rho = 0.05$, $\gamma = 0.8$, and $b = 0.3$. Use the interactive figure to find the level of w^c . Can you verify it algebraically?
- Now assume also that $B = 0.2$, $\underline{u} = 0.02$, and $t = 0.4$. Check on the graph what are the equilibrium hours of employment (H^N) for the w^c you found above. Can you derive it algebraically?
- Increase the value of barriers to entry (b) to 0.4. What is the effect to the number of firms entering/exiting the market? What happens to w^c and H^N ? Explain.
- Imagine a policy intervention that increases the unemployment benefits (B) to 0.3. What happens to w^c and H^N ? Explain.
- Imagine an increase to the productivity of labour (γ) to 0.95. What happens to w^c and H^N ? Explain.

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