Papers

2. Student Preferences when *Explaining* Dynamics

Student Preferences when *Explaining* Dynamics

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Abstract

This article presents the results of four survey experiments in which undergraduates indicated their preferences for methods of explaining macroeconomic dynamics. Each comparison was between a conventional method (e.g., equations or graphs) and a system dynamics-based method (e.g., stock-and-flow diagrams or feedback loops). A significant majority of students indicated a preference for using system dynamics methods when explaining dynamics.

JEL: A22, C91, E21, E23, E32
Key words: education, experiment, feedback, graph, macroeconomics, model, stock,

> The following depicts an actual Apple Macintosh television commercial:
>
> *Two company executives, Steve and Bill, look out over a large office area where each desk has either a Mac or a PC. They notice that about half the employees are working hard and the other half are wasting time. They wonder aloud about the difference in productivity.*
>
> *Steve says, "Look! The busy employees are the ones using the Macs."*
> *Bill replies, "Sure, but that can't explain productivity. People like using Macs."*

Unlike Bill in the TV commercial, we expect a connection between preference and performance, and that is one motivation for research on student learning preferences. This article examines preferences of students placed in the hypothetical role of tutor to a well-educated layperson and required to choose a supplementary teaching tool. Section 1 elaborates on the rationale for this study of student preferences. Sections 2 and 3 summarize the conventional and alternative teaching methods that are the basis for the "teaching tools" in the experiments. Section 4 describes the setting and outcome of each experiment. The results are discussed in section 5.

1. Why Preferences Matter

The practical significance of the findings in this study rests on the premise that student preferences matter. There are at least three reasons for this presumption. First, experimental findings by Nowaczyk et al. (1998) and Sankaran et al. (2000) show a positive relationship between preference and performance among undergraduates. Closely related to learning preferences are self-described learning styles and expressions of self-efficacy in learning situations. Terry (2001) documents the correlation between self-described learning styles and performance, and Stevens et al. (2004) show that a student's sense of self-efficacy has a significant association with performance.

A second reason that preferences matter is the expectation that student interest in a topic affects future course enrollments. When Becker and Watts (1998, p. 8) compared the prevalence of traditional "chalk-and-talk" methods of teaching economics with more innovative methods, they found that students preferred the non-lecture approaches. They concluded:

> *Student preferences certainly aren't the only measure of instructional effectiveness and value, but they do count for something, ceteris paribus, and together with student grades, it seems plausible that they are related to future enrollments in upper-division economics courses.*

Thirdly, we care what students think about our teaching. The value they attach to our work matters to us professionally and personally. Moreover, student reluctance to embrace our teaching tools makes our instructional task harder. To the extent that it also reduces our effectiveness, student learning suffers, and we may find ourselves choosing a new teaching method to improve our productivity. An example of such a strategy is the widespread reliance on static graphs instead of mathematical models in economics principles courses, where most students are unprepared for overt mathematical instruction and have a strong aversion to such methods.

2. Conventional Methods

The mathematical complexity of economic analysis has become a hallmark of the profession. However, the mathematical aptitude and/or training necessary for working with modern economists' models are rarely found among the attributes and experience of undergraduates. For that reason, undergraduate economics instruction relies more on graphical models than mathematical models, as this account from Kennedy (2000, p. 2) vividly portrays:

> *Students learn to analyze economic phenomena through economic models, formalized with graphs and, at advanced levels, algebra and calculus. Much time is devoted to learning how to manipulate various graphical and algebraic models that have come to serve as an intellectual framework for economists…. At the undergraduate textbook level, the technical dimension is predominantly in the form of graphical analysis…. At advanced levels the technical dimension is dominated by algebraic formulas in which Greek letters play prominent roles.*

The extent to which undergraduate economics students actually learn by studying graphs is a question addressed elsewhere (Wheat 2007b, c). The focus here is on student preferences when a choice has to be made between using conventional or alternative methods of supplementing a verbal explanation. The conventional tools are equations and static graphs, while the alternatives are based on the feedback loop diagrams.

3. The Feedback Method

This section briefly explains the stock, flow, and feedback loop terminology and diagramming methods used in system dynamics-based instruction. The purpose is to acquaint the reader with the "alternative" tools available to the students in the experiments. The students, however, did not receive such an explanation.

Over the past five years, a new instructional method has been developed for teaching macroeconomics.[1] Called the *feedback method*, it aims to make economic dynamics accessible to students who lack the mathematical training normally considered a prerequisite for such access. For example, students do not manipulate equations or rely exclusively on static graphs for visualization of dynamics. While the pedagogical approach is new to economics, it fits within a tradition of feedback thinking in the intellectual history of economics documented by Richardson (1991).

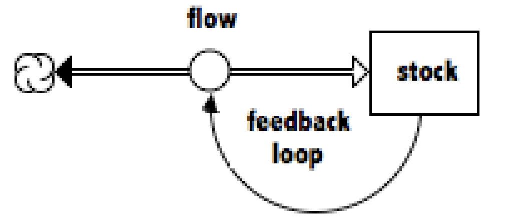

Figure 1. Central Concepts in System Dynamics

The conceptual building blocks for the feedback method are *stocks*, *flows*, and *feedback loops*. These are also the central concepts in system dynamics, a method for studying and managing problems in complex feedback systems (Figure 1).

A *stock* is an accumulation of material (e.g., inventories) or information (e.g., sales data that are collected and analyzed prior to decisions about future production). A *flow* is the rate of change in a stock. Mathematically, the stock integrates the flow.[2] In the first experiment, the alternative teaching tool was a simple one-stock model (method A in Figure 9). In the other three experiments, the alternative teaching tool was a feedback loop diagram (method A in Figures 10, 11, and 12). A *feedback loop* is a closed loop of mutual causation that occurs over time. One sometimes sees references to *intertemporal* feedback loops. However, since feedback always requires some passage of time, the adjective "intertemporal" is redundant. The loop diagram has a stock-and-flow conceptual foundation, as illustrated in Figure 2. When working with stock-and-flow models of complex systems such as an economy, the relative simplicity of the loop often makes it a more useful tool for communicating with non-specialists (e.g., undergraduates).

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[1] The macroeconomics principles course is delivered via the Internet to students enrolled at Virginia Western Community College in Roanoke, Virginia.

[2] System dynamics models are systems of differential equations. Typically non-linear and without analytic solutions, they rely on numerical integration (e.g,, Euler or Runge-Kutte methods) to generate simulated behavior. See Sterman (2000, chapter. 6 and 7 and Appendix A) and Ford (1999, chapter 3).

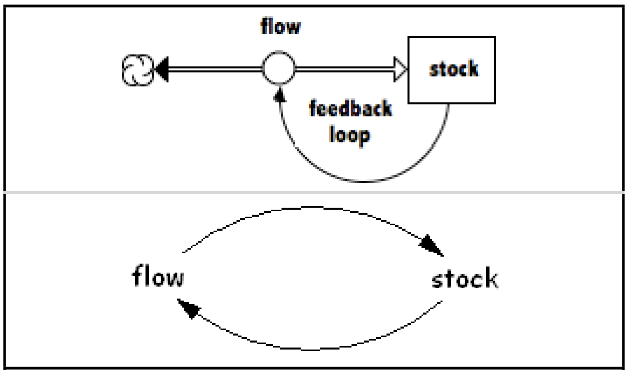

**Figure 2. Stock & Flow Diagram (top)
converted to
Feedback Loop Diagram (bottom)**

A loop must contain at least two causal links, which are *ceteris paribus* hypotheses about cause-and-effect. A causal link is a word-and-arrow diagram similar to those that appear in some economics textbooks (e.g., Kennedy 2000 and Sexton 2002). Sexton (p. 269), for example, uses an arrow pointing up (↑) or down (↓) in front of a variable to show whether it is increasing or decreasing in value. He uses a horizontal double-arrow (==>) between a "cause" and an "effect." To express the hypothesis that supply influences price, for example, Sexton would write the expressions in Figure 3. His symbolic language says (top) an increase in supply would cause a decrease in price, and (bottom) a decrease in supply would cause a price increase.

↑ supply ==> ↓ price
↓ supply ==> ↑ price

Figure 3. Sexton Diagrams

Figure 4 shows how both versions of the hypothesis would be explained in a single system dynamics causal link.

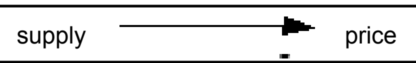

Figure 4. System Dynamics Causal Link

The minus sign (-) in Figure 4 means that price would *decrease* if supply *increased*. If the supply *decreased*, then price would *increase*. In other words, the negative polarity is suggestive of two variables moving in opposite directions. If the link had been labeled with a plus sign (+), that would suggest two variables moving in the same direction.[3] Thus, the interpretation of the link polarity is similar to the interpretation of a correlation coefficient. However, system dynamics models connect variables that have causal rather than merely correlational relationships.

[3] If the first variable is a *flow* and the second variable is a *stock*, then a plus (+) sign should be interpreted as "addition" to the stock. A minus (-) sign would indicate "subtraction" from the stock. For example, production *adds* to inventories, and sales *subtract* from inventories.

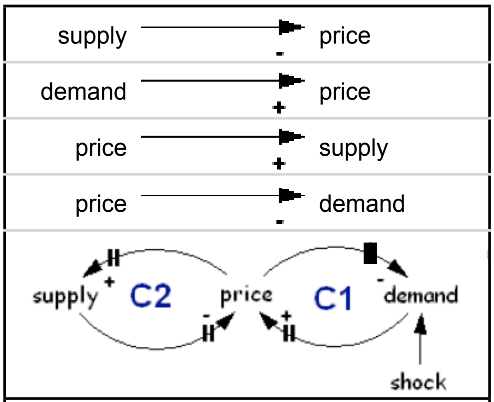

Figure 5. Four Links (top) combined into Two Loops (bottom)

Combining links is a straightforward process after each two-variable relationship has been hypothesized. Consider, for example, the four links in the top of Figure 5, relating supply, demand, and prices. Implicit in those four links are the two feedback loops at the bottom of that figure. After an exogenous shock to demand, the simulated behavior arising from the hypothesized feedback structure is shown in Figure 6.

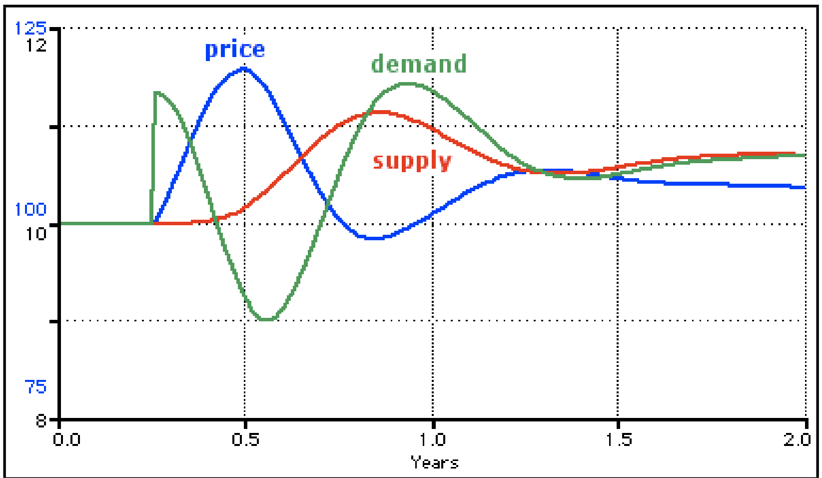

Figure 6. Simulated Behavior of Fig. 5 Model

To interpret the behavior in Figure 6, use the feedback structure in Figure 5, where the cross marks (||) indicate time delays. Begin by assuming that a permanent exogenous demand shock disturbs the equilibrium. After suppliers take time to evaluate the reliability of the signal that demand has increased, price would rise. The rising price would, in turn, put downward pressure on demand, but the full effect would occur gradually. Meanwhile, suppliers respond to the rising price by stepping up production, but it takes time to organize the requisite factors of production. When supply eventually responds, that puts downward pressure on prices, but with a delay. In Figure 6, the damped oscillatory behavior and the amplitude and period for each curve depend on parameter assumptions for delay times and price elasticities.

When a feedback loop contains an *odd* number of negative signs, it will counteract or negate a previous trend.[4] Such loops (e.g., C1 and C2 in Figure 5) are called *negative* or *counteracting* or *balancing* loops. Each term has the same meaning, and they are used interchangeably. The other type of feedback loop is called *positive* or *reinforcing*; again, the terms are synonymous. Figure 7 illustrates the reinforcing loop implicit in the familiar wage-price spiral hypothesis. A "walk-around-the-loop" shows that it feeds on itself and reinforces an initial trend. Confirmation comes from counting an *even* number of negative links (namely, zero) around the loop.

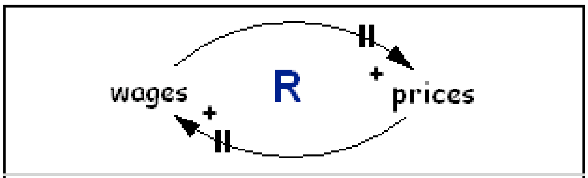

Figure 7. Reinforcing Feedback Loop

4. The Experimental Design

The students participating in the experiment were to assume they had a mythical Aunt Sally who wanted to learn something about economics. The general instructions stated:

> *Assume you have an Aunt Sally who has no training in economics. However, she is a bright person who can understand clear explanations. She has four questions for you. In each case, you will have to select one teaching method for your explanation, and you will have two alternative methods from which to choose. Your task in each case will be to select the method you believe would be more helpful to your explanation.*

The motivation to hypothetically involve an intelligent but non-specialist third party —Aunt Sally—was two-fold. First, with the tutor perspective oriented towards someone other than the instructor, the student is less likely to respond in a "teacher-pleaser" way. In addition, making Aunt Sally a bright layperson forces students to think about what constitutes a clear explanation for an audience of educated generalists. Since less than one percent of students taking the introductory course will major in economics, they are not destined to be specialists (in economics, at least). Aunt Sally, then, is the personification of future adult characteristics of the students in the experiment. Their preference for methods of tutoring can be taken as an expression of their own learning preference.

Each question from Aunt Sally required a specific task and constituted a separate experiment. In each case, students had to indicate which teaching method they would use to answer her question, with the choice being a conventional method (equations or graphs) or an alternative method (stock-and-flow diagrams or feedback loops). Expressing a preference was operationally defined as making a choice between two teaching methods for the purpose of explaining economic structure or behavior. Let C represent the conventional method and A represent the alternative method. For each of the four experiments (E = 1...4), let P_{CE}

[4] This is analogous to the multiplication rule involving negative numbers: when multiplying a string of numbers containing an odd number of negatives, the product will be negative.

represent the percentage of students preferring the conventional method and P_{AE} the percentage of students preferring the alternative method. The null hypothesis for each experiment was

$$H_{0E}: P_{CE} = P_{AE}$$

and the results were evaluated by t-tests for proportions at a 0.05 significance level.

Student preferences were recorded in a survey conducted with forty-nine students in the author's introductory macroeconomics course, first with summer students in May 2006 and then with fall students in August 2006. The survey was administered very early in each course before students received any instruction utilizing the teaching tools involved in the experiment. The results were pooled for analysis.

Summary of Results. Figure 8 summarizes the results of the four experiments. In three (E1, E2, and E4), the null hypothesis was rejected. In the third experiment (E3) there was no significant difference between the two methods.

experiments & options		results	p
E1	C: equations A: stock-and-flow	P_{C1}: 12% P_{A1}: 88%	.00
E2	C: equations A: feedback loop	P_{C2}: 6% P_{A2}: 94%	.00
E3	C: graph (equilibrium) A: feedback loops	P_{C3}: 54% P_{A3}: 46%	.57
E4	C: graph (disequilibrium) A: feedback loops	P_{C4}: 30% P_{A4}: 70%	.01

Figure 8. Summary of Results

Experiment 1. In the first experiment (E1), Aunt Sally's question was about the relationship between production, sales, and inventories. Here is the text presented to each student:

> *You need to provide Aunt Sally with a clear explanation of the relationship between production, sales, and inventories. To do that, you must choose between the two alternative methods of explanation listed as Method C and Method A in the figure below. Which method would you select?*

The figure to which the students were referred is reproduced in Figure 9. The choice was between a simple differential equation (method C) and a simple stock-and-flow diagram (method A).[5] The task in the first experiment was motivated by Richmond's (1997) demonstration that system dynamics software has the potential to make dynamics accessible to economics students lacking mathematical sophistication. His presentation begins with a simple business cycle model expressed as a set of differential equations. One of the

[5] The student instructions actually referred to methods 1 and 2 rather than C or A, respectively. In this paper, all diagrams from the experiment have been modified to refer to methods C and A.

equations—change in aggregate inventories defined as the difference between aggregate production and sales—has been reproduced in Figure 9 as method C. After completing a full exposition of the mathematical model, Richmond repeats the same "lesson" in business cycle modeling using *STELLA*[6] software. Method A reproduces the portion of his system dynamics model that corresponds to the differential equation in Method C. The inventory stock accumulates the net flow of production and sales. The underlying equation specifies that the level in the stock at time *t* is equal to the level at the time of the previous calculation (*t-dt*) plus the net inflow during the subsequent calculation interval (*dt*).

*inventories(t) = inventories(t - dt) + (production - sales) * dt*

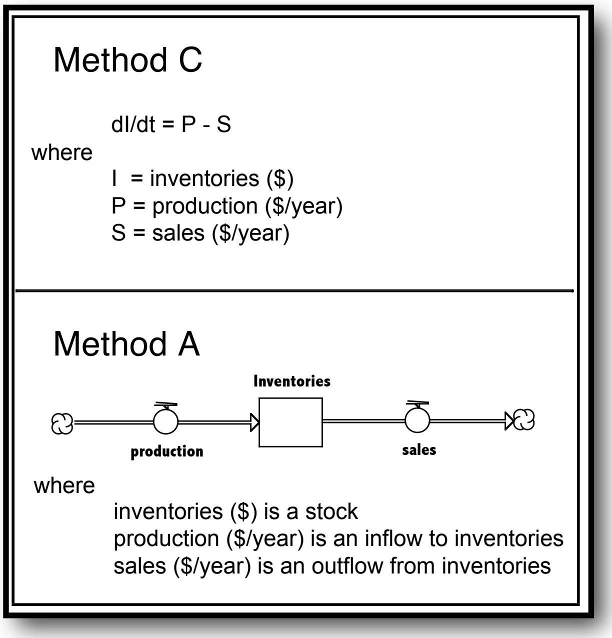

Figure 9. Experiment 1 Diagram

However, the students in the experiment do not see the stock *equation*. The diagram in method A is intended to provide a visual stimulus to the intuitive idea that any change in the level of the stock would be due to a difference between inflows and outflows. In an actual instructional setting, students would learn the "bathtub" analogy—with inflows of water adding to the level in the tub and outflows subtracting from the level— although such a hint was not provided in this experiment.[7] Richmond's hypothesis is that system dynamics models can enable students to grasp "sophisticated dynamics without complex mathematics." Experiment 1 does not test that hypothesis.[8] However, it does test an implicit sub-hypothesis; namely, that students will *prefer* an intuitive method for learning dynamics that does not require training in complex mathematics.

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[6] *STELLA* is a registered trademark of isee systems (http://www.iseesystems.com)

[7] The bathtub analogy is a staple of the system dynamics introduction to stocks and flows. Perhaps the earliest published use of the metaphor by an economist was in Boulding (1945), where he referred to the "bathtub theorem" in discussing the rate of accumulation in stocks.

[8] See Wheat (2007b and c) for tests of that hypothesis.

Forty-nine students participated in the first experiment, and forty-three selected method A, the stock-and-flow diagram ($P_{A1} = 88$ percent). The t-value was 7.99 with 49 degrees of freedom, and $p < 0.0001$ in a two-tail test. The null hypothesis was rejected.

Experiment 2. In the second experiment (E2), the students had to give Aunt Sally a lesson about mutual causation in the macroeconomy. This experiment was also motivated by Richmond's (1997) comparison of business cycle models. Method C in Figure 10 is a simplified adaptation of the mathematical model's expression of the relationships between aggregate production, income, and sales. Method A is a simple feedback loop representation of those relationships, adapted from Richmond's stock-and-flow model. Of course, both methods are incomplete pictures of the overall dynamic process, since they do not reveal limitations on the aggregate reinforcing structure.

In some ways, method A in Figure 10 is reminiscent of the standard circular flow diagram found in macroeconomics textbooks. However, the feedback loop—and its stock-and-flow heritage—has important distinctions from the customary circular flow diagram. The feedback loop is not just a material flow of dollars or a material flow of goods and services. It also includes a flow of information from the sales rate in one time period to the production rate in a later time period. Moreover, it is the information about income that drives the spending of the dollars that comprise income. Information accumulates in a stock, and it is the changes in perceived information that affects subsequent behavior.

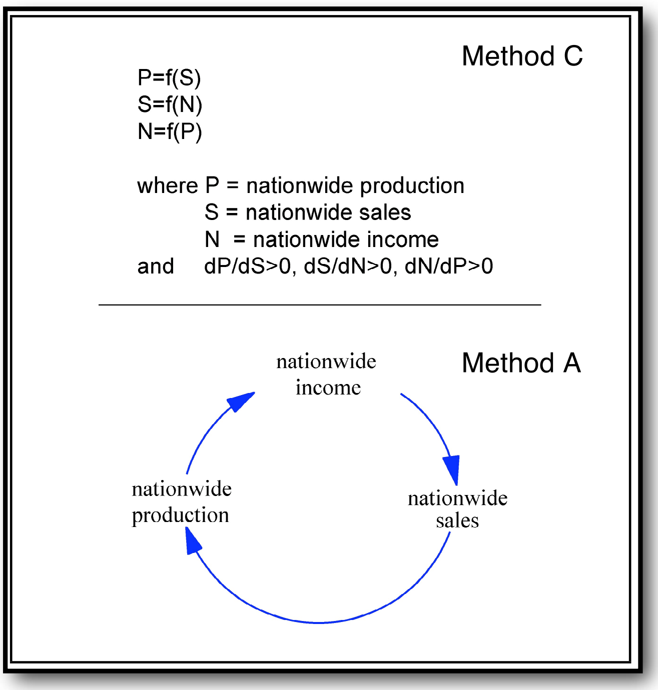

Figure 10. Experiment 2 Diagram

In the interest of simplicity and also to minimize the potential for bias, link polarities are not labeled with plus signs (+), the delay marks (||) are not shown, and the loop is not labeled as a reinforcing loop. For the loop to be appealing to the students, the circular arrows must be intuitively consistent with the causal process described in the instructions to the tutor.

Since the experiment was conducted early in the course, the students lacked preparation for tutoring Aunt Sally on this topic. Therefore, their instructions included a simplified summary of the process described in standard macro textbooks:

> *Next, you will explain to Aunt Sally the relationship between production, income, and sales nationwide. Here is what she needs to learn: "After nationwide production increases, nationwide income eventually increases. After nationwide income increases, nationwide sales eventually increase. And, after nationwide sales increase, nationwide production eventually increases." You must choose between alternative methods of explanation in the figure below: Method C or Method A. Which method would you select?*

The choice presented to the students is reproduced in Figure 10. Almost all students selected the feedback loop to teach Aunt Sally this lesson about macroeconomics ($P_{A2} = 94$ percent). The t-value was 12.7 with 48 degrees of freedom, and $p < 0.0001$ in a two-tail test. Again, the null hypothesis was rejected.

Experiment 3. In the third experiment (E3), students were given these instructions:

> *Now Aunt Sally wants to know about the relationship between disposable income, saving, and consumption. (Disposable income is after-tax income; i.e., "take-home pay." Consumption means consumer purchases.) Looking at the diagrams below, would you choose Method C or Method A for your explanation?*

To supplement their explanation, students had to choose between a static graph (C) and a feedback loop diagram (A) in Figure 11. Method C is based on the Keynesian Cross, the featured model in most introductory macroeconomics textbooks during the mid-20th century (Colander 1995). As a representation of the static relationship between disposable income, saving, and consumption—the crux of Aunt Sally's question in E3—the graph seems to be ideally suited for this tutoring task. In addition, the graph scales enable students to approximate the numerical relationships.

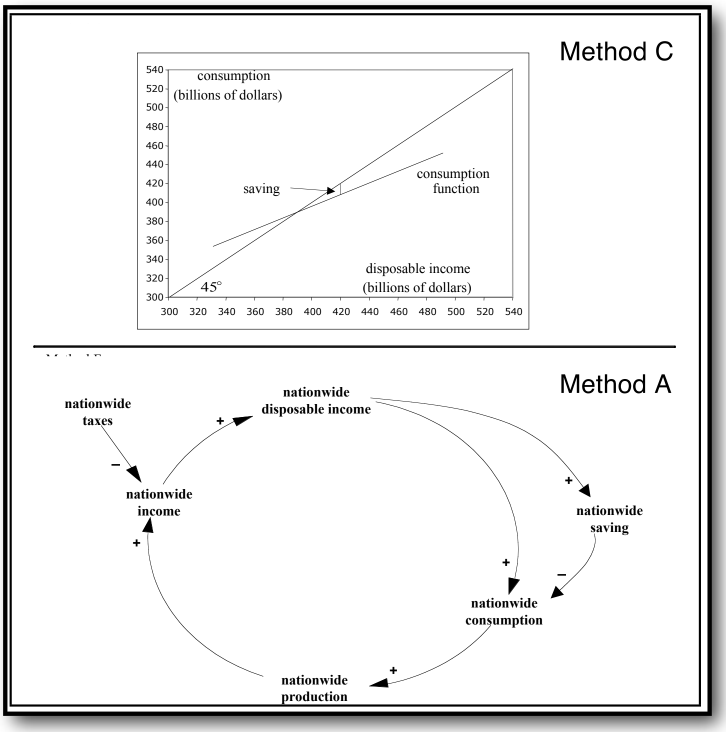

Figure 11. Experiment 3 Diagram

Method A in Figure 11 contains two feedback loops and both positive and negative links (without explanation). Moreover, the loop introduces an exogenous tax to complete the definition of disposable income. Clearly, the loop diagram in E3 is more complex than the one in the previous experiment. Its purpose is to show how saving affects consumption over time, although Aunt Sally's question seems to need only a static explanation. It would not have been surprising to see a significant percentage of students preferring the graph method over the feedback loop diagram. The design of E3, in fact, seems tailor-made for rejection of the null hypothesis, in favor of the graphical method of instruction. There was no statistically significant difference between method C and method A. Despite the design features that seemed favorable to the graph, nearly half of the students preferred the feedback loop ($P_{A3} =$ 46 percent). The t-value was only 0.573 with 47 degrees of freedom, and the null hypothesis was not rejected.

Experiment 4. The last task required selecting a teaching tool to help Aunt Sally understand business cycles. Since the students had no preparation for such an explanation, their instructions provided a theory and a choice of tools to help explain the theory. This was the most difficult of the four tasks because the unfamiliar theory was summarized in just one sentence, and the diagrams representing two supplementary tools were much more complex than in previous experiments (Figure 12). The students' conventional option was the AS/AD model, which has largely replaced the Keynesian Cross in textbooks (Colander 1995).[9] When the feedback method (A in Figure 12) is used in an actual macroeconomics course, the pair of loops is used to illustrate how an economy's tendency to feed on itself—the reinforcing loop —can be moderated by a counteracting loop. Moreover, when the counteracting loop contains significant delays due to material and/or information stock adjustments, oscillations occur.

The task in E4 was to explain the so-called sticky price theory of business cycles, using either the AS/AD model or the feedback loop model. Here are the instructions:

> *Finally, Aunt Sally wants an explanation of business cycles. Suppose you believe the theory that says, "If prices adjust slowly to changes in demand, GDP will deviate more from its long-run trend." Looking at the diagram below, would you select Method C or Method A to help you explain that theory?*

A significant majority of students preferred the feedback loop method ($P_{A4} = 70$ percent). The t-value was 2.86 with 45 degrees of freedom, and $p < 0.01$ in a two-tail test. The null hypothesis was rejected.

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[9] Method C in Figure 12 is adapted from Hall & Taylor (1997, ch. 8-9), Mankiw (2002, ch. 9; 2004, ch. 20; 2007, ch. 15). Mankiw (2002) uses horizontal short-run aggregate supply (SRAS) curves, while Mankiw (2004 and 2007) uses upward sloping SRAS curves. Hall & Taylor use horizontal lines that imply a price-determining intersection with the AD curve, but do not explicitly refer to the lines as SRAS curves.

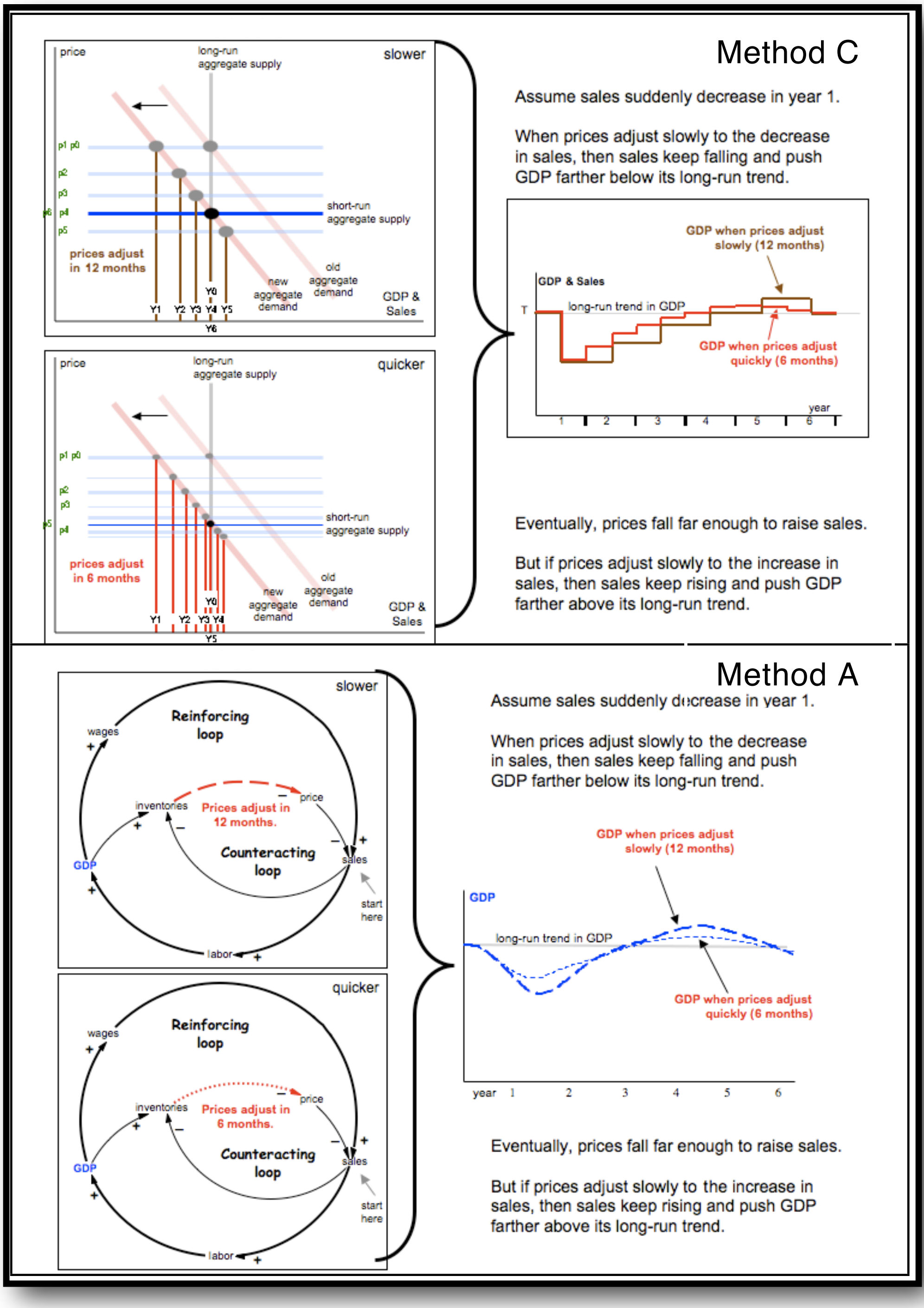

Figure 12. Experiment 4 Diagram

5. Discussion

The set of experiments presented four hypothetical situations designed to shed light on undergraduates' first impressions when encountering a choice of tools to facilitate teaching economic dynamics. None of the students had ever received instruction or training in system dynamics or systems thinking. In contrast, nearly forty percent of the students had taken a prior economics course and had some experience with graphs and at least simple equations. Some students later mentioned having seen circular cycles in science textbooks, but it is virtually certain that none had ever seen such feedback loops in an economics context.

In the first two experiments (E1 and E2), students displayed an aversion to equations. They preferred a stock-and-flow diagram and a feedback loop over equations by wide margins. Such a strong student aversion to overtly mathematical models provides economics instructors with a strong incentive to use alternative instructional models in introductory courses. Historically, that incentive has led to widespread reliance on static graphs. However, in the last two experiments, static graphs did not evoke the response from students that graph advocates might expect. In E3, despite what could be considered an ideal setting for preferring a graph, there was no significant difference in the proportion of students choosing one method or the other. In E4, when the question clearly required communicating *dynamic* relationships, a significant majority preferred the feedback loop. These results suggest that the value of static graphs depends on the condition being explained. When a graph was used to display *equilibrium* conditions in a simple static situation (E3), the graph had as much appeal as the feedback loop. However, when the graph was used to demonstrate *transitions between equilibria* (E4), the students showed a clear preference for the feedback loop. In other words, for explaining economic *dynamics*, students preferred the feedback loop over the graph.

Even in the static E3 task, where students were about equally divided, there may be an explanation for the graph's parity with the loop that has more to do with familiarity than preferences. Two-thirds of those with some prior economics coursework chose the graph, while less than half of those without economics experience chose the graph. While analysis of the small sub-samples was not statistically significant,[10] the controls suggest that the feedback loop method might have been preferred if all students in the sample had been equally unfamiliar with the teaching methods.

During the survey, the students were also required to provide reasons for the preferences they expressed, and those reasons are summarized in Figure 13. A subjective process was used to summarize the students' explanations. As the reasons were reviewed for each experiment, key phrases were recorded in a list. Then the key phrases were examined for commonalities, and the list was pruned to the ten categories shown in Figure 13, to which all reasons were assigned. Each cell entry within the four experimental columns reflects the number of times a particular reason was given by students to explain their choices. In E1, for example, eight students gave reasons that could be categorized as "just easier to understand or explain." When offering those reasons, three were referring to the C method and five were referring to the A method. The last two columns on the right convey different information. Those cells show—*for all experiments*—whether a particular reason was more likely to be given by a student preferring method C or method A. For example, "concrete numerical example" was a reason given only by students who preferred the C methods. In contrast, "shows mutual causation" was given only by students who preferred the A methods.

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[10] In a tabular analysis of economics course experience and the choice between methods A and C, the chi-square values was 1.81 ($p < .20$).

Thus, for a given reason in a row, the percentages in the last two columns suggest the relative significance of *that reason* for preferring the C or A methods.[11]

The *minority* of students—those preferring the equations or graphs—displayed a much higher regard for methods that provided concrete answers for the purpose of illustrating computations, moving towards equilibrium, or just solving problems. The *majority* of students—those preferring the system dynamics methods—were much more likely to stress the importance of visualizing a process and were unlikely to "see" anything meaningful in an equation. Moreover, they tended to recognize *processes* (including mutual causation) in the stock-and-flow diagram and the feedback loops, despite the fact that few (if any) had ever seen such diagrams prior to the experiments.

Reasons Given by Students (categorized)	Experiments								pct. of total within row	
	E1		E2		E3		E4			
	C (6)	A (43)	C (3)	A (46)	C (26)	A (22)	C (14)	A (32)	C (%)	A (%)
plug in the numbers to get answer	3								*100*	*0*
similar equations in prior economics course	1		1						*100*	*0*
concrete numerical example					18		2		*100*	*0*
shows movement toward equilibrium							3		*100*	*0*
just easier to understand or explain	3	5	1	11	9	9	7	16	*33*	*67*
describes a process	1	23	1	17	2	16	2	9	*8*	*92*
importance of seeing or visualizing		18		11		1			*0*	*100*
pictures better than math		13		10					*0*	*100*
easier for people without prior knowledge		8		2				1	*0*	*100*
shows mutual causation				13		9		10	*0*	*100*

Figure 13. Students' Reasons for Choices in Each Experiment
Within each column, reasons (in cells) may exceed choices (in parentheses) because some students gave more than one reason. Last two columns show percentages within groups across rows.

Further Research. A primary purpose in an introductory course should be to enable students to comprehend basic economic processes. If there is a link between preference and performance, these experiments cast doubt on the value of equations and graphs in facilitating attainment of that primary course goal, while suggesting that the feedback method

[11] Note that the "100 percent" figures for rows 1, 2, and 4 are based on very small cell entries.

could be helpful. The undergraduate aversion to mathematical models—and, therefore, the limitations of such models as teaching tools—is well appreciated by economics instructors. Instructor satisfaction with graphs, therefore, may be relative; i.e., *relative to equations*. Indeed, when compared to mere verbal instruction, the pedagogical value of graphs is questionable (Cohn et al. 2001).

This paper began with the premise that student preferences matter, at least in part, because of the hypothesis that preference affects performance. The results reported here suggest that research on the preference/performance question should give attention to the role that process visualization has on both student learning preferences and student learning efficiency. The results presented here suggest that there is a place for both graphs and feedback loops in the macro instructor's toolkit, and future research should also examine how the tools can be used in complementary ways. It may be, for example, that exercises in feedback thinking may facilitate graphical understanding, as the following student comment during E4 suggests.

> *Method 1* [graph] *is a weird graph. I have never interpreted something that complex. But then as I began to understand the second method* [loops]*, I was able to understand more about the first method* [graph].

These experiments demonstrate the intuitive appeal of system dynamics models and their potential to activate student thinking about complex economic processes. Activated thinking does not guarantee comprehension, of course, but it is a necessary first step in that direction.

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Appendix: Data from Four Experiments

student	Economics?	SD?	E1	E2	E3	E4
1	no	no	C	A	A	A
2	yes	no	A	A	C	--
3	yes	no	A	A	C	A
4	yes	no	A	A	A	C
5	no	no	C	A	C	C
6	yes	no	A	A	A	--
7	no	no	A	A	C	A
8	no	no	A	A	A	A
9	no	no	C	A	C	A
10	yes	no	C	C	A	A
11	no	no	A	A	C	A
12	yes	no	A	A	C	C
13	yes	no	C	A	C	A
14	no	no	A	A	C	C
15	yes	no	A	A	C	A
16	yes	no	A	A	C	C
17	yes	no	A	A	--	A
18	no	no	A	A	A	A
19	no	no	A	A	A	A
20	no	no	A	A	A	A
21	no	no	A	A	C	C
22	no	no	A	A	A	A
23	yes	no	A	A	A	A
24	yes	no	A	A	C	A
25	no	no	A	A	C	C
26	no	no	C	A	A	A
27	no	no	A	A	C	C
28	no	no	A	C	C	C
29	yes	no	A	A	C	C
30	yes	no	A	A	A	A

Appendix: Data from Four Experiments

student	Economics?	SD?	E1	E2	E3	E4
31	no	no	A	A	A	C
32	no	no	A	A	C	C
33	no	no	A	A	A	--
34	no	no	A	A	A	A
35	yes	no	A	A	A	A
36	no	no	A	A	C	A
37	no	no	A	A	A	A
38	no	no	A	A	A	A
39	yes	no	A	A	C	A
40	no	no	A	A	C	A
41	no	no	A	A	C	A
42	yes	no	A	A	C	A
43	no	no	A	A	A	A
44	no	no	A	A	A	A
45	yes	no	A	A	C	A
46	yes	no	A	A	C	C
47	no	no	A	A	A	A
48	no	no	A	C	A	A
49	no	no	A	A	C	C
n	49	49	49	49	48	46
mean*	0.388	0.000	0.878	0.939	0.458	0.696
st. dev.	—	—	0.331	0.242	0.504	0.465
t**	—	—	7.99	12.70	0.58	2.86
df	—	—	48	48	47	45
p	—	—	< 0.0001	< 0.0001	.5692	< 0.0064

*For means, no = 0, yes = 1, C = 0, A = 1. ** For t-test, null hypothesis for proportion: 0.50