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Technology Improves Learning in Large Principles of Economics Classes: Using Our WITS[*]

Sheryl B. Ball
Dept. of Economics
Virginia Tech
Blacksburg, VA 24061
sball@vt.edu

Catherine C. Eckel
School of Social Sciences
University of Texas at Dallas
Mail Station GR31
Richardson, TX 75080
eckelc@utdallas.edu

Christian Rojas
Dept. of Economics
Virginia Tech
Blacksburg, VA 24061
crojas@vt.edu

Abstract:

Much recent innovation in teaching economics has focused around active learning strategies, which are often difficult or impossible to implement in large classes. We have developed a system that uses handheld devices and wireless technology to facilitate interactive learning in large classes by putting technology in the hands of the students during class. The Wireless Interactive Teaching System (WITS) consists of handheld wireless devices, a laptop server, and proprietary software. Students use the WITS system to trade in markets, play standard economics games, take multiple choice quizzes, and communicate with the instructor during class. This paper reports results of a controlled experiment to test the effectiveness of the WITS system using two 80-person principles of economics classes. Student who used the WITS system earned final grades that averaged 7 points higher than the control class, adjusting for other important influences on grades such as demographics, ability and experience. The impact on learning is highest for freshmen and women students, groups who often struggle with introductory economics, and lowest for male seniors, who, in our sample, tend to be engineering majors. Teaching evaluations are also significantly higher in the experimental class.

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I Introduction

Much recent innovation in teaching economics has focused around active learning strategies and the use of technology on learning. At the same time, budget realities make large lecture classes a fact of life for principles of economics courses at many universities. Unfortunately, neither active learning strategies nor teaching with technology tend to work well in large classes: active learning is difficult to facilitate with many students and learning with technology in economics has been limited for the most part to classes small enough to fit in computer labs.

We have developed a system that uses handheld devices and wireless technology to facilitate interactive learning in large classes by putting technology in the hands of the students during class. The Wireless Interactive Teaching System (WITS) consists of Handspring Visors (a handheld PDA device) equipped with wireless capabilities, a laptop server, a wireless access point and projector, and proprietary software. The system forms an intra-net using the 802.11b wireless standard. The WITS system allows students to trade in markets, play standard economics games (prisoners' dilemma, public good, 2x2 matrix, etc.), take multiple choice quizzes, and communicate with the instructor during class. (See http://lshta.vt.edu/index.html for a sample exercise and instructional material.) This paper reports the results of an experiment to test the impact of the WITS system on classroom learning.

Previous studies have investigated the learning effect of hand run experiments in small classes. The most commonly cited work on this topic by Gremmen and Potters (1977) reports on results from the use of a single macro/international exercise in three sections with a total of 38 students. They find a significant and educationally meaningful difference in learning between the groups. In another test of learning using a single exercise, Frank (1997) finds increases in homework scores when students participate in an experiment based on the commons problem. Emerson and Taylor (2004) and Dickie (2004) both measure learning outcomes at the beginning and end of the semester using the Test of Understanding in College Economics (TUCE). By adding eleven exercises in small (roughly 30 student) classes, Emerson and Taylor find a significant increase in scores compared with control sections. Dickie tests the effects of incorporating seven experiments into the micro principles curriculum using three sections of about 50 students each, one of which was a control. He finds a significantly larger improvement in scores on the TUCE by the experimental group. Cardell et al. (1996), however, find that adding four classroom experiments does not yield statistically significant improvements in student outcomes.

In fall 2003, we conducted a controlled experiment to test the effectiveness of the WITS system using two 80-person principles of economics classes at Virginia Tech. Our study differs from previous work in three important ways: First, use of the WITS system allows us to implement experiments in larger classes. Second, we measure learning using data on exams scores, rather than the TUCE. Improved results are, therefore, understandable in terms of students' grades, the metric that students and universities use to evaluate class performance. Finally, on the days when our experimental class participated in an exercise, the control class discussed research results from the same experiment, including reading the experimental instructions. This way we are able to isolate whether the improvements in learning are from substituting experiment-based material for standard lectures, or whether gains are a result or active or passive learning.

Students who used the WITS system earned final grades that averaged approximately 7 points higher than the control class, adjusting for other important influences on grades such as demographics, ability and experience. The impact on learning is highest for freshmen and women students, groups who often struggle with introductory economics, and lowest for male seniors, who, our sample, tend to be engineering majors satisfying a general education requirement. Teaching evaluations are also significantly higher in the experimental class.

II. Experimental Design

Our test of the effectiveness of classroom experiments involved two matched Principles of Economics classes taught in Fall, 2003. Both classes had 80 students enrolled at the beginning of the term. They were taught in the same classroom, back-to-back, with 50 minute class periods beginning at 10:10 and 11:15 am on Monday, Wednesday and Friday. Syllabi for the courses were identical including assignments, grading weights and dates on which course topics were covered. We did not indicate until after the deadline to register for classes that these classes were part of an experiment to improve teaching to avoid any selection bias. During the semester we did not indicate which section was the experimental and which the treatment class. The students in our sample constitute about 10 percent of the total number of students in micro principles that semester. Only two of eight sections of micro principles offered in Fall 2003 were part of the study because of limited data collection resources.

We designed the curriculum for the two classes to cover standard topics in microeconomic principles, except for the inclusion of the exercises. To assess the impact of using experimental exercises in the classroom, we kept the class material constant across the two sections. The experimental class incorporated seven classroom exercises: a posted offer auction, an auction with buyer and seller-side taxes, a public goods game, a commons problem, a monopoly exercise, a set of 2 x 2 matrix games, and ultimatum and dictator games. We did not use the quiz or communication features of WITS, even in the experimental class, to improve experimental control. The curriculum for the control class included seven "research days" where we discussed the material covered by the exercises. The parallel lecture in the control class consisted of reading through the instructions, and a presentation of research and classroom results from those games. Both classes were told they were test classes for curricular innovation: one for the interactive exercises, and the other for the research days. Students were not informed that a comparison was being made between different approaches in the two classes, and seemed unaware of any differences.

On days where experiments were conducted, devices were distributed to students in the experimental class during class and collected at the end. Students logged into the system with an ID number that allowed us to keep track of their decisions and scores. They then interacted with the system via a series of user-friendly, touch-sensitive screens. For example, in the auction, each student saw a screen displaying his cost information, and made a choice of what price to charge by touching the screen. Each student received individual information about cost, and entered individual decisions about selling price; at the end of the exercise, each student received individual feedback on sales and profit. The server collected and aggregated information (including the price distribution of the units sold), and displayed it to the class.

Each of the seven modules for the experimental class contained five elements.

1. **Instruction**. This element involved instructions read by the students before class, as well as in-class instruction. The materials read by the students focused on the

incentive structure and procedure for the exercises, while the in-class component involved interacting with the technology.

2. **Exercise**. The exercises were conducted during class time, and normally used a full class period. This element included participating in several variations on the exercise, some of which were suggested by the students.
3. **Follow-up**. For each exercise, care was taken in the next class period to review the experience, and to clearly make the connection with the theoretical material related to the exercise. This often included a brief presentation of related research results.
4. **Homework**. Following the exercise, students had to complete a homework assignment (post-exercise evaluation). These involved answering standard problems for the relevant economic concept, reflecting on the experience and results in the classroom, and applications of the concepts learned. In addition, students sometimes completed problems based on the data from the exercise.
5. **Evaluation**: Each module included a pre-exercise evaluation, examining the student's knowledge coming into the class. Some of the pre-exercise questions were also on the homework. In addition, students completed 4-6 questions evaluating the experience.

In the control class, students participated in seven modules on the same topics. They completed identical homework assignments relating to the modules and grades on the assignments were weighted the same in determining the students' class grades. Assignments in both classes all multiple choice format problems to eliminate instructor grading bias and for ease in scoring. Instead of conducting the classroom experiments, however, the instructor discussed results from published experiments similar to those conducted in the WITS class. In the control class, the classes that paralleled the classroom experiments in the experimental section were organized following a format like a research seminar, with descriptions of why the experiments were conducted, how they were implemented (including sample instructions), followed by results taken from published research or previous experiments conducted by the experimenters. The amount of time spent on normal course lectures was kept constant across the classes. For example, the class plan for the experiment on competitive markets was as follows:

Element	Control Class	Experimental Class
Instructions on how to trade in an auction market	Read Instructions before class	Read Instructions before class
Pre-test	Short in class quiz about supply and demand	Short in class quiz about supply and demand
Exercise	View data from a market experiment with data before and a demand shift (50 minutes).	Use WITS to trade in a market both before and after a demand shift. Observe data from experiment (50 minutes).
Follow Up	Review the exercise and connect it to lecture material on supply and demand.	Review the exercise and connect it to lecture material on supply and demand.
Homework	Answer standard questions on supply and demand.	Answer standard questions on supply and demand. (same questions as control class.)

To assess the effectiveness of the technology-enabled exercises, we use pre- and post-exercise evaluations (post-exercise evaluation scores counted for students' homework grades in both sections) for each of the seven modules and parallel final exams. We used multiple choice exams to evaluate student achievement because they are the standard evaluation tool in principles courses at Virginia Tech because of large class sizes and have the advantage of avoiding instructor grading bias. At the beginning of the semester, data on demographics (age, class, gender and major), experience (whether a student took economics in high school) and ability (GPA, High School rank and math SAT score) were collected.[1] At the end of the semester, standard teaching evaluation forms were supplemented with a more extensive evaluation form, which included questions on students' perceptions prior to the class, their experience with economics, their perception about the usefulness of experiments, and students' assessment of the class compared to others.

III. Sample Characteristics

After dropping incomplete observations, the data include 64 students in the control class and 62 in the experimental class.[2] As is typical of the principles course at Virginia Tech,

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[1] We also collected verbal SAT scores, however, math SAT scores had higher predictive power and both scores could not be included in our analysis due to strong correlation.

[2] 6 students in the experimental class and 8 students in the control class dropped the course; because this number is similar across treatments, we have some confidence that there was an endogenous response to either treatment.

students cover a broad range of majors, and include undergraduate students at all levels. Twenty percent of students come from business majors, while 50% of students are from engineering, science, or math. The rest of the enrolment is from a diverse collection of majors.

Table 1 shows the characteristics of the two classes. The variance of all variables (measured by their standard deviation) is approximately the same for the two classes. The results of tests for differences in means across the two samples are presented in the last column of the table (with p-values in brackets). The two groups are demographically similar. Average age is between 18 and 19; approximately 75% of students in both classes (combined) are 19 or younger. The experimental group is slightly older on average, though there is no difference in the distribution of class attainment (freshmen, sophomore, junior, senior). Approximately 30% percent of students in both groups are female. A larger percentage of students in the experimental group had economics in high school (% Econ in HS).[3] Although average high school rank is significantly higher in the experimental class, the difference in mean math SAT scores is not significant.

III. Results

A. Aggregate measures

Our analysis focuses primarily on the final exam grade, which is the most objective measure of overall learning in the two classes. Both classes were given very similar final exams written in multiple choice format. Care was taken that each question was matched with a counterpart on the other exam. A core set of identical questions was included that focused on the learning objectives of the experimental exercises. On average, students in the experimental class scored 3.2 points higher (77.45) on the final exam than did those in the control class (74.25). This difference is statistically significant at the 10% significance level.

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5 students in the experimental class and 3 students in the control class did not take the final exam. 3 observations in the control class and 7 observations in the experimental class were dropped because no SAT score was available. Two outliers in the control class were ignored. One corresponded to a student that marked option ‘A’ as the answer for all the questions in the final exam (his score was 24 out of 100 points). The other outlier was a student that scored 42 out of 100 in the final exam; it was dropped because it significantly affected our normality and heteroskedasticity diagnostic tests. The rest dropped the class, failed to fill out the initial assessment/survey, or failed to take the final exam.

[3] The use of categories instead of actual values for the age and high school rank variables is due to the way the initial survey was constructed. While attempts were made to recover more precise values, there was a large number of missing observations.

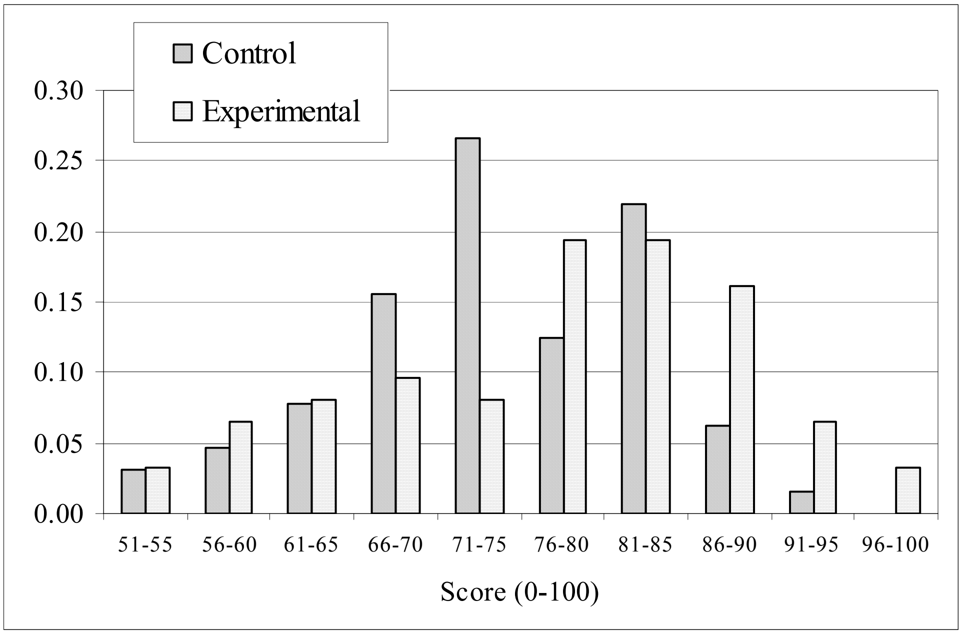
Figure 1 shows the distribution of the final exam grades in the two classes. The distribution of grades for the experimental class is clearly shifted to the right with respect to the distribution of the control class indicating higher grades using the WITS system.

Table 1: Demographic Summary Statistics
(Standard deviation)

Variable	**Control n=64**	**Experimental n=62**	**Min**	**Max**	**Two tail t-test [p-value]**
Age (category) 1=17 years or younger, 2=18-19, 3=20-21, 4=22 or older	2.031 (0.50)	2.313 (0.59)	1	4	2.97 [0.00]
Class 1=Freshman, 2=Sophomore, 3=Junior, 4=Senior, 5= Graduate, 6=Other	1.625 (1.06)	1.758 (0.94)	1	6	0.75 [0.46]
% Female 0=Male, 1=Female	26.6	30.6	0	1	0.50 [0.62]
% who took economics in high school 0=No Econ, 1=Econ in HS	3.13	16.13	0	1	2.53 [0.013]
High school rank* 1=below 50%, 2=21-50%, 3=11-20%, 4=6-10%, 5=2-5%, 6=top 1%	3.54 (1.19)	3.98 (1.20)	1	5	2.00 [0.05]
SAT (math)	616 (80)	628 (76)	450	800	0.88 [0.38]

*** For High School Rank, the number of available observations is 59 for both classes.**

Figure 1: Distribution of Final Exam Grades



B. Regression Results

Given the differences between the two class populations, it is important to conduct multivariate analysis to control for individual student characteristics. The baseline for the econometric results is an OLS regression that has the final grade (in percentage format) as the dependent variable and an experimental dummy together with demographics, experience and ability measures as the explanatory variables. In addition, several interactions of explanatory variables with the experimental dummy were created with the objective to test whether experiments have a different effect on the performance of distinct demographic groups. These results are shown in Table 2, which contains the estimates for three different specifications.

The explanatory variables include a dummy for whether a student was in the experimental class (EXP), demographic measures (age, class, gender and major), experience (whether a student took economics in high school) and ability (high school rank and math SAT score).[4] In addition to these variables, several indicator variables for different majors and groups of majors (for example a dichotomous variable for business and non-business majors) were created and it was found that none of these carried significant coefficients or substantially affected the remaining relationships in the specifications we tested.[5]

The first specification contains only the experimental dummy (EXP) and is displayed for comparison purposes with the other two. It shows that there is a statistically-significant difference in the final exam grade between the two classes of 3.20 points. The second specification includes demographics (but not interaction terms) and it can be seen that a similar difference in grades (close to 4 points) remains after controlling for all demographic, experience and ability variables.

The third specification includes the interaction terms that were found to be significant. This specification also omits Age since the significance is very low and its inclusion increases the standard errors of the remaining coefficients. The negative coefficient on the interaction of the experimental variable and Class (EXP*Class) indicates that students that have just begun their university studies (freshmen) benefit more (where the benefit is measured by their final grade) from the use of experiments than do students that have been in school for some time.

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[4] Because a large number of our subjects were first semester freshmen, we were not able to collect consistent college GPA information, so this ability measure was not useable.

[5] The available choices for major in the actual survey were: a) Economics (Business), b) Economics (Arts and Sciences), c) Other Business, d) Engineering/Science/Math, e) Social Sciences, f) Humanities/Arts, g) Education, h) Architecture, and i) Other.

The coefficient on the interaction of the experimental variable with Female (EXP*Female) provides evidence that females benefit more from experiments than do males. Some diagnostic tests on the residuals were performed for specification III; the corresponding p-values are presented at the bottom of the table. Test results revealed no departures from standard normality or heteroskedasticity assumptions.[6]

Table 2: OLS Results
Dependent Variable: Grade on Final Exam
(t-statistics)

Explanatory Variables	**Specification**		
	I	II	III
EXP	3.202	2.212	7.366
	(1.81) *	*(1.35)*	*(2.35)* **
EXP*Class			-3.832
			(-2.48) **
EXP*Female			5.537
			(1.58)
Class		0.669	2.090
		(0.82)	*(2.07)***
Female		0.833	-1.518
		(0.46)	*(-0.60)*
Econ in HS		-1.906	-1.616
		(-0.71)	*(-0.62)*
HS Rank		1.176	1.098
		*(1.78)**	*(1.70)**
SAT (math)		0.066	0.063
		*(6.26)****	*(6.05)****
Constant	74.250	28.063	28.593
	*(59.74)****	*(7.33)****	*(3.94)****
# Observations	126	118	118
R-squared	0.026	0.318	0.362
Adjusted R-squared	0.018	0.282	0.315

Residual Diagnostic Tests for Specification 3 (p-values):
Null hypothesis of Normality: Shapiro-Wilk (0.12), Skewness-Kurtosis (0.34);
Null hypothesis Heteroskedasticity: White (0.47), Breusch-Pagan (0.61)

*** Significant at 1%, ** at 5%, * at 10%

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[6] A fourth specification (not shown) added a variable "SAT LOW", which is a dummy variable equal to 1 for students with math SAT scores in the lower 10% of the sample and its interaction with the experimental treatment. While the coefficient on the interaction is statistically significant, its sign is consistent with previous studies that suggest very low ability students may not benefit from including experiments (Dickie, 2004).

In order to better visualize the varying magnitude of the effect of experiments on the performance of different demographic groups, scores were simulated for 8 distinct Class-Gender pairs (class: freshman, sophomore, junior, senior; gender: male, female).[7] For each pair, two scores were simulated, one assuming that the student did participate in the experiment while the other assuming the student did not. Hence, there are 16 simulated scores. Table 3 shows the simulated scores for each Class-Gender pair with a 95% confidence interval in parenthesis.[8]

Table 3: Simulated Final Exam Scores by Demographic groups

Class / Gender	**Male**		**Female**	
	Control	Experimental	Control	Experimental
Freshman	75.27 (72.52-78.02)	80.21 (77.29-83.12)	69.93 (65.46-74.39)	83.64 (78.74-88.53)
Sophomore	71.93 (69.11-74.75)	72.53 (69.64-75.44)	73.60 (69.26-77.93)	76.63 (72.52-80.74)
Junior	71.99 (68.04-75.93)	73.44 (68.99-77.89)	73.37 (68.25-78.49)	78.23 (73.74-82.72)
Senior	81.50 (76.09-86.91)	68.28 (62.06-74.50)	N/A* N/A	75.70 (69.71-81.69)

Note: These simulated values are computed using the estimates from specification III shown in table 2. For each Class-Gender pair in the table, the mean of the remaining variables (SAT, HS Rank and Econ in HS) over the individuals in each cell is used to calculate the predicted final exam score. 95% confidence intervals in parenthesis.
* No students in the sample match the criteria of this cell.

The table shows that as students have more years of school, the impact of teaching with experiments decreases. The benefit of the use of experiments for freshmen males is approximately 5 percentage points; however, this benefit almost disappears for sophomore and junior males and for senior males it appears that the use of experiments may have a negative effect. The impact of using experiments on the female students is stronger. Freshmen

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[7] 125 out of the 126 students involved in the study fall into these categories.

[8] This interval is calculated as: $x\hat{b} \pm s\sqrt{c'(x'x)^{-1}c}$, where x is the matrix of covariates, $\hat{b}$ is the vector of the estimated coefficients, s is the square root of the sum of squared errors (divided by the degrees of freedom) and c is the vector containing the values of the covariates for which we are simulating the score.

females benefit the most from experiments by improving their scores by approximately 14 percentage points. This impact decreases as female students accumulate more years of experience in college.[9]

C. Impact on Teaching Evaluations

The impact of the WITS system was also measured using standardized teaching evaluation given at the end of the semester. The experimental students provided higher scores for almost all questions. However, there is a significant difference in means for only three questions. On a four-point scale (1= poor, 2=fair, 3=good, 4=excellent), students in the experimental class assessed the instructor as more successful in communicating the subject matter (3.16 vs. 2.83, p=.056) and found the class more stimulating (3.18 vs. 2.78, p=.008) than did students in the control class. In addition, the overall rating of the professor by the experimental class was higher than that by the control class (3.32 vs. 3.07, p=.095). Students in the two classes rated remaining elements of the class as the same, including knowledge of subject matter, concern or respect for students, fairness in grading, administration of the class, educational value, and effort required. We infer from this that students did not perceive that the students in the two classes were treated differently by the instructor. Nevertheless, using experiments significantly affected overall evaluations in a positive way.

IV. Conclusion

This paper focuses on the impact of using our WITS – a system of wireless-equipped handheld devices – to facilitate interactive exercises in teaching micro principles of economics in large classes. Overall, the impact on learning is strongly positive, with larger impacts on freshmen students and on women, two groups who often struggle with introductory economics. In addition, students' evaluations on key questions were higher for the experimental class, showing that students found the classes more stimulating than the control class.

A critical question that remains largely unanswered is why students learn more when interactive exercises are used in class. Those of us who have been teaching with experiments for years believe we have an intuitive answer: both we and the students enjoy the classes more and so engage with the material more fully. The fact that students enjoy their classroom

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[9] The comparisons and inference for juniors and seniors (for both males and females) is less reliable because only few students in the sample are in these two categories.

experience more also may make them think more about the subject matter, or spend more time discussing it with their friends. In Ball, Eckel and Rojas (2005) we explore this question further, and provide some evidence that students learn to ask different, more advanced or application-oriented questions after participating in an experiment. One reason for this is the flexibility built into the WITS system that allows instructors to test student-generated hypotheses. If a student asks questions such as, "What would happen if there was only one seller?" or "What would happen if the returns to cooperation were higher?" our approach is to help the student develop the question into a testable hypothesis. The system is design so that instructors can easily change the parameters of the game and "test" the student's hypothesis.

Our system differs from the Personal Response Systems (PRS) currently marketing in conjunction with several economics texts. Since many faculty members are now familiar with this system, we are frequently asked to compare it to WITS. First, PRS devices have a small number of buttons which limits input into the PRS. Second, the flexibility of the system is limited. Since they do not have display screens, students cannot bid in markets, or participate in games, such as the public goods game, that require random matching into small groups. Because they have no "memory", the PRS cannot store data for students to retrieve later on. Third, communication is one way. Students cannot receive individualized data, such as costs or values for market trading, or receive feedback on their performance in the exercise. Despite their limitations, we like to think of the PRS as a primitive version of WITS. Assessment of its value in teaching should provide useful information for refining the development of WITS.

We believe in the importance of continuing assessment efforts in economics in an attempt to better understand why teaching innovations succeed or fail, especially where technology is concerned. Walstad (2001) discussed general issues involved in assessment of economic education, and notes the wide variety of assessment techniques beyond the standardized test. However, to us, the assessment of teaching technology carries special challenges because instructors often adopt technology without thought to its impact on learning. An example would be the widespread move to Powerpoint lectures, which has gone largely unassessed. Failures of teaching technology are documented in Oppenheimer (2003) who bemoans the tendency of technology adoption to diminish rather than enhance creativity.

It is very important to continue to assess changes in teaching practice in order to evaluate their impact on learning, using a broad variety of assessment techniques.

At the same time that assessment evidence mounts that interactive exercises improve teaching effectiveness in economics, it also has become easier for instructors to adopt this approach. While the WITS system is still under development, other avenues are available for using experiments in small and large classes. Bergstrom and Miller (1999) collect a number of classroom experiments that can be conducted by hand in a standard Principles of Economics class, though the exercises are for the most part oriented toward smaller sections. Charles Holt provides a bibliography of published experimental exercises as well as pdf files of his own (http://www.people.virginia.edu/~cah2k/teaching.html). These publications contain exercises designed to teach particular points in economics, not only at the principles level (e.g., competitive markets, public goods, how banks create money) but also in more advance classes (collusion, coordination, information cascades, strategic voting). The papers explain how to conduct the experiment, and how to integrate the exercises into the standard curricula and may also contain suggestions for problems and homework assignments.

For classes with access to computer labs, several options are available. Holt has developed Veconlab, an online site for conducting experiments via the internet (http://www.people.virginia.edu/~cah2k/programs.html). His site includes a wide variety of exercises with flexible parameters. Econport, a digital library of economics materials housed at the University of Arizona, also maintains a site for conducting online experiments (www.econport.org). Both sides are somewhat short on teaching materials, making them more appropriate for experienced users. For instructors who want to try experiments for the first time, Aplia is a great place to start. Founded by Paul Romer, Aplia provides support for teaching that includes several internet-based experimental exercises designed to be conducted outside of class. Teaching materials, homeworks, etc., are integrated into the user-friendly Aplia system. Instruction on using interactive exercises in teaching is provided under the American Economic Association's Teaching Innovations Program (TIP). For the past few years, Holt and his colleagues also have conducted NSF-sponsored workshops in using experiments to teach, which emphasize the use of technology to facilitate classroom experiments.

When things get dull in a chemistry class, the instructor can start a fire or blow something up. In economics, we have no interesting chemical reactions to fall back on. Interactive experiments give us a way to capture the attention and imagination of our students, improving the learning experience and enhancing learning. Technology can help us extend interactive learning to larger classes. Our work suggests the importance of building flexibility into the design of such technology.

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