Report on Outcomes from Gateway Sciences Initiative Project “Active Learning In General Physics”

Julian Krolik and Robert Leheny
Department of Physics and Astronomy

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I. Executive Summary

Under this project, the Department of Physics & Astronomy has carried out curriculum development to integrate more fully “active learning” methods into the General Physics curriculum. The project included two main elements:

(i) A delegation of faculty, along with a graduate-student representative, made a series of site visits to other universities to learn about best practices in introductory physics teaching and to identify the style of instruction most appropriate to JHU. The major outcome of this study was the creation of a new track in General Physics modeled on the SCALE-UP course developed at North Carolina State University and the TEAL course developed at MIT. This track is being offered for the first time in the 2013-2014 academic year. Initial assessment and feedback from the fall semester indicate the course has a positive impact on the students enrolled. The department plans to continue offering this new track for the foreseeable future.

(ii) For versions of General Physics taught in a conventional lecture format, the Department has developed curricular materials for the discussion sections centered on group problem-solving activities. This effort was significantly informed by our site visits. The Department has also initiated a TA orientation program to prepare graduate teaching assistants to lead discussion sections in this new format. The active-learning discussion sections were piloted in spring 2013 and are now employed in all General Physics courses. The curricular materials developed through the project, stored in a wiki that allows instructors to add and edit items, are expected to be a dynamic and growing resource for faculty teaching General Physics in the future. Early feedback and assessment indicate that the new discussion section curriculum improves student learning and student satisfaction.

II. Background

Physics underlies virtually all of engineering and is an essential support to the other sciences. For this reason, General Physics is a required course for nearly all majors in the Whiting School and for many majors in the Krieger School. Nearly 60% of all JHU undergraduates take General Physics, approximately 700 students in any given semester. Thus, General Physics is a significant part of the undergraduate experience at JHU. Both to provide material tuned to student interests and to make class sizes more manageable, the Department of Physics and Astronomy has for many years offered General Physics in two versions, one for physical sciences and engineering students (171.101/171.102) and the other for biosciences students (171.103/171.104). A third, much smaller course sequence is offered for prospective Physics majors (171.105/171.106).

Historically, the General Physics courses at Johns Hopkins have been taught in a traditional way, with 3 hours of lecture given by a professor and 1 hour of instruction in
problem-solving by a graduate-student teaching assistant per week. Most students taking General Physics also take concurrently the corresponding lab course. Although we have continually made efforts to improve instructional quality in General Physics, three decades of physics education research (PER) have demonstrated that traditionally structured classes are not nearly as effective as those applying “active learning” methods in which students spend at least part of their class time working on problems and/or in-class experiments, typically in small groups, while the instructor circulates. In particular, conceptual understanding, as opposed to problem solving by pattern recognition, is imparted more thoroughly through these approaches. As part of the University’s Gateway Sciences Initiative, we have set out to integrate more fully “active learning” methods into the General Physics courses at Johns Hopkins.

III. Site Visits

Since multiple approaches to implementing active-learning methods in introductory physics have shown success at peer institutions, we decided that before identifying appropriate strategies for JHU we needed to understand these methods and their various realizations in greater depth. For that reason, a delegation from the department conducted a series of visits to other universities during spring and early fall 2012 to observe their approaches and to discuss the implementation and degree of success of these approaches with faculty, teaching assistants, and students who have first-hand experience with them. A total of eight schools were included in the visits: Princeton, Tufts, MIT, Harvard, Cornell, University of Minnesota, University of Washington, and North Carolina State University. The structure of the introductory physics courses at these schools varies considerably, from lecture-plus-recitation formats similar to that at JHU to formats in which lecturing is nearly absent. However, our conclusion is that these differences result less from differing philosophies about how best to implement active-learning methods than from institutional constraints such as the ratio of students taking physics to faculty teaching it, classroom architecture, and TA support. Further, while inspired efforts can successfully integrate active-learning methods within a traditional lecture format, the lecture auditorium is clearly a suboptimal venue, and the outcomes are often uneven. As a result, those schools, such as U. Washington and U. Minnesota, that are constrained to a lecture-plus-recitation format due to very large enrollments in introductory physics have focused much of their energy on improving the quality of instruction in the recitation section, often with good success. (Indeed, our curriculum development efforts for the discussion sections described below benefitted greatly from observing recitation sections at these schools and from discussing the teaching approach with faculty and graduate assistants there.) Further, where active learning methods are implemented more comprehensively, specifically within the SCALE-UP classes at NC State and the TEAL classes at MIT (described below), we were very impressed with the engagement of the students and the quality of learning taking place.

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1 Participants in the site visits included Professors of Physics & Astronomy Julian Krolik, Robert Leheny, Daniel Reich (Department Chair), Bruce Barnett, Timothy Heckman, David Kaplan, and David Neufeld, and senior PhD student Matthew Walters.

2 TEAL stands for “Technology-Enabled Active Learning.” SCALE-UP originally stood for “Student-Centered Activities for Large Enrollment Undergraduate Physics,” but now, to better reflect the teaching approach and the fact that the method has been adopted in subjects other than physics, it stands for “Student-Centered Active Learning Environment with Upside-down Pedagogies”
Statistics collected by these institutions support our observations with demonstrated improvements in student learning. With this in mind, we have implemented a set of initiatives for General Physics at JHU to integrate such strategies into our program.

IV. Descriptions of Reforms

Our reforms of JHU General Physics have had two objectives. First, we have established policies and practices that make active-learning methods an aspect of all General Physics classes retaining the lecture-plus-recitation format, particularly through new teaching approaches in the discussion sections. Second, we have introduced a new track for General Physics in which the lecture-plus-recitation is replaced by classes in which active-learning activities occupy the great majority of class time. The instructional style for this new track emulates the SCALE-UP approach originally developed at NC State. To achieve these objectives, we have taken the following four steps:

A. Institutionalized cooperative group learning in General Physics discussion sections.

B. Institutionalized TA training to prepare graduate TAs to teach successfully in an active-learning format.

C. Introduced a SCALE-UP-style course sequence (171.107/108) for up to 84 students as a track in General Physics for Physical Sciences Majors, with the intention that this track could eventually be expanded to accommodate the bulk of General Physics students.

D. Promoted the use of other active-learning strategies, such as peer instruction, in all General Physics classes.

In the sections below, we describe each of these initiatives in more detail.

A. Active Learning in Discussion Sections

Although some instructors have employed elements of activity-based learning in General Physics discussion sections (e.g., Prof. Bruce Barnett pioneered the use of online problem-solving activities as part of discussion sections), in most cases discussion sections have been devoted to graduate TAs working through homework problems at the blackboard for students. The benefits of this exercise to the students are unclear but seem limited; sections often were poorly attended and received low ratings in student evaluations. We therefore identified the implementation of active learning methods, specifically centered on exercises employing cooperative group problem solving, into all the discussion sections as the single most effective measure for improving the quality of the General Physics courses. Observations from our site visits to other universities indicated that successful cooperative group learning relies on carefully designed materials. With this in mind, lesson plans drawn from current best practices for applying active-learning strategies in physics instruction, but tailored to the course syllabus and the student body at JHU, were developed for the discussion sections of Physics I and Physics II. The resulting plans are a mixture of concept-oriented tutorials like those pioneered by the PER group at the University of Washington and “context rich” problems constructed following the problem-writing strategies developed by the PER group at the University of Minnesota. The tutorials and problems cover more than 30 topics spanning the syllabi of 171.101/102 and 171.103/104, usually with 4-6 problems and exercises for each topic.
so that instructors and TAs can tailor the content for each section. (Although our original GSI proposal described plans for developing new curriculum only for Physics I, we have in fact completed problems and exercises designed for cooperative group learning for both the first and second semesters of the course sequence.) The lesson plans were piloted in spring 2013 and are being employed in all General Physics courses in the 2013-2014 academic year. Early feedback, described in the Section V below, indicate that the redesigned sections are having a positive impact on student learning and student satisfaction. A library of the problems and activities that have been developed is housed in a wiki on JShare (https://jshare.johnshopkins.edu/mwalte18/GSI_Work/) so that faculty and TAs with access can edit and add content. In this way, we anticipate that the library will grow and become a sustained resource for faculty and graduate students teaching General Physics in the years ahead.

B. TA Training and Undergraduate Learning Assistants

A recognized shortcoming of the department’s teaching has been the uneven preparation of entering graduate students who serve as TAs. This issue becomes potentially acute with the adoption of cooperative group learning in the discussion sections (and in the SCALE-UP style class described below), where the approach taken by the TA is important for the success of the lessons, but this instructional style is likely unfamiliar to many entering graduate students. To address this issue, we have initiated TA training sessions for entering PhD students to introduce them to effective teaching methods, with particular focus on successful leadership of cooperative group learning sessions. Run for the first time in August 2013, the training is integrated into the orientation of all first-year graduate students in the department. It involves three contact hours between the faculty and senior TAs leading the orientation and the first-year students. It includes practical instruction on how to organize and lead a discussion section employing cooperative group learning and background on the pedagogical motivation for this teaching method to ensure “buy-in” from the TAs. It also includes instruction on more general teaching practices, such as grading. During the training, each new TA is given the opportunity to role play both as an instructor and as a student participating in cooperative group problem solving. Immediately afterward, they are given constructive feedback on their performance. The training session will be a regular feature of the orientation for first-year students in the future. A handbook, which is distributed as part of the training, was written to provide the TAs with a reference document with instructions on running “active learning” discussion sections, as well as other useful information for navigating what for many PhD students is their first experience with teaching.

Although we believe the TA training should help prepare the graduate teaching assistants who lead the sections for this experience, our impression from institutions where cooperative group learning in recitations has been extensively tested is that our staffing level of one TA for 24 students is inadequate for teaching in this format. As an economical way to provide additional support, we have initiated a policy of supplementing the TA in each discussion section with an undergraduate learning assistant. The main responsibility of the learning assistant is to partner with the graduate TA in circulating through the classroom as the students work on the problems and exercises. The learning assistants have no grading responsibilities. Our initial impression from student feedback is that the learning assistants are a positive addition to the General Physics instruction.
C. Introducing SCALE-UP Instruction in General Physics

As stated earlier, from the impression we obtained from our site visits and from further studies of best practices in physics instruction, we see the SCALE-UP method developed at NC State and elaborated in the TEAL classes at MIT as potentially the best instructional method available, consistent with the need to teach 700+ students each semester. However, full implementation in the General Physics courses at JHU will require considerable added resources in the form of more faculty assigned to General Physics and classroom renovations. Therefore, we have opted to introduce it in stages, beginning with one section (171.107/108) for students in the physical sciences and engineering taught in a SCALE-UP-style mode. This new sequence is being offered for the first time during the 2013-2014 academic year.

1. What is SCALE-UP?

As in the studio and workshop approaches that have found success at liberal arts colleges where enrollments in General Physics are small, SCALE-UP courses replace traditional lectures and recitations (and typically labs) with a single class setting where students work through activities in small groups, usually comprised of three students. In contrast to these smaller-scale settings, in SCALE-UP integrated technology and appropriate classroom architecture enable comparable educational success even with student/faculty ratios ranging from 50:1 to 100:1. The approach draws heavily on two major innovations in physics education. The first of these is the idea of cooperative group learning, which holds that students learn most effectively in settings where they are forced to explain—and defend---their ideas to one another. The other is the idea of the “flipped classroom.” Rather than devote class time to a lecture that comprehensively introduces the course material, in SCALE-UP students initiate their exposure to a topic by completing readings or web-based tutorials before class. Class time is instead devoted to student activities in which they apply the new ideas in ways that build and reinforce their understanding. A typical SCALE-UP-style class is broken up into 5 to 15 minute segments in which the students work cooperatively on a problem or activity, interspersed with brief, class-wide discussions. As students work through problems and activities in their groups, the instructor and TAs circulate and monitor progress, providing guidance as needed using Socratic methods. Lecturing is not fully eliminated, but is limited to a small fraction of the class time and is used primarily to motivate topics and to summarize and contextualize key concepts.

2. Implementing SCALE-UP at JHU

A key requirement of teaching SCALE-UP physics courses is classroom space suited for this style of instruction. To accommodate the new course, space in Bloomberg 478 (PUC Lab/Advanced Lab) was renovated during summer 2013. Included in the renovated space are round tables that each seat nine students, movable chairs, a speaker's podium with controls for electronic projection, several large-screen monitors, two projectors and screens, and a large set of white boards covering nearly all available wall space. Each table is equipped with a microphone to facilitate student participation in class-wide discussion. The space is designed to accommodate a class of up to 84 students. Funds for the renovation were not part of the GSI
grant, but were provided by the KSAS Dean and the JHU provost’s office. At times when Physics 107/108 is not using the space, we have made it available to instructors of other classes who want to pilot active-learning formats that might benefit from this classroom architecture. During the 2013-2014 academic year two Chemistry courses (Applied Chemical Equilibrium and Reactivity (030.103) and Chemical Structure and Bonding (030.204)) as well as a number of General Physics discussion sections are being taught in the space.

Curriculum development for the new SCALE-UP-style course also took place during summer 2013, led by Prof. Robert Leheny, who taught the first semester of the sequence in fall 2013, and by Prof. Petar Maksimovic, who is teaching the second semester in spring 2014. To facilitate the curriculum development, they drew on the work at NC State and MIT. Both the NC State PER group and the developers of TEAL at MIT have generously provided access to their libraries of detailed lesson plans. Some of the exercises and activities developed for the discussion sections described above have also been adapted for the SCALE-UP class.

Unlike in the TEAL class at MIT and the SCALE-UP class at NC State, formal labs are not being incorporated into the JHU SCALE-UP class; instead, students in the class continue to take the separate lab course like their counterparts in the lecture-based General Physics course. However, many topics in introductory physics lend themselves nicely to experimentation. To reinforce student learning, we have therefore also developed exercises incorporating hands-on experiments, or “tangibles”, performed cooperatively by small groups of students in the same way that they work out problems. The main purpose of the tangibles is not to conduct rigorous, quantitative measurements but to make concrete what are otherwise abstract ideas and to allow students to test their conceptual understanding by comparing predictions against observations. Funds to outfit the SCALE-UP courses with the equipment and supplies that the students employ in these simple experiments have been made available through the second round of grants in the Gateway Sciences Initiative.

D. Active Learning in Lectures

In parallel with the implementation of SCALE-UP style instruction and the improvements to the discussion sections described above, the Department has actively encouraged those teaching the lecture-based sections of General Physics to incorporate peer instruction methods in their lectures. Any realistic scenario for fully converting General Physics courses to SCALE-UP-style instruction will take several years. Also, the department might ultimately find that offering both SCALE-UP-style and lecture-based versions has the advantage of expanding options for students. Hence, innovations that positively impact instruction in lectures will remain a crucial part in assuring an improved learning experience for all students in General Physics. For example, as part of this initiative, Prof. David Neufeld employed peer-instruction strategies similar to those pioneered by Eric Mazur at Harvard in teaching 171.101 in spring 2012 and 2013 and in fall 2013. Beyond the improved learning experience we believe this approach has offered, his teaching has enabled us to perform comparative assessment between an active-learning-based class taught primarily in an auditorium and the new SCALE-UP class. Some of the results of this comparison are described in the next section.
V. Assessment

A. Impact of Active Learning in Discussion Sections

In spring 2012 and 2013, students in Physics I (171.101) were given the Force Concept Inventory (FCI), a widely used diagnostic test of learning gains, to measure the impact of the redesigned discussion sections. They took this quiz both at the beginning of the semester and at the end so that we could see how much the students learned during the class. Students showed markedly larger gains in 2013 (gain of 0.31 in 2013 versus 0.20 in 2012); however, additional improvements to the course between 2012 and 2013 (notably the greater familiarity of the lecturer with peer-instruction methods) make interpreting the contribution from the discussion sections difficult. Student evaluations at the end of each semester also showed marked improvement in student satisfaction with the discussion sections (3.98 out of 5 in 2013 versus 2.32 out of 5 in 2012). We note that the spring version of Physics I is the “off-sequence” offering of the course, which has much smaller enrollment than Physics I in the fall. Piloting the new discussion sections in this smaller course enabled us to monitor the teaching in the discussion sections more easily, which likely influenced the gains that we observed. We anticipate some challenges in maintaining high student satisfaction as we expand their use to the large General Physics courses. For example, in fall 2013, evaluation of student satisfaction with the discussion sections in Physics I indicated that it was not as high as the gain seen in the spring 2013 (2.94 out of 5). We will continue similar assessments of the discussion sections in future years as we revise and modify the active-learning format and the TA training.

B. Assessment of SCALE-UP Course

In fall 2013, the FCI was once again given at the beginning of the term and at the end, but this time both to students in the new SCALE-UP course and in the main Physics I, which was taught in an auditorium using peer-instruction methods. In addition, the students in conventional 101 and SCALE-UP 107 were given the same exams, both midterms and finals. The results of these exams are shown in Table 1. As the FCI pre-test scores indicate, students in SCALE-UP 107 displayed marginally weaker preparation, but performed slightly better on exams. Indeed, although the differences are small, the SCALE-UP students did better on all three midterms and the final. Similar comparisons will be made in future semesters to track how much success our classroom innovations are achieving.

<table>
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<th>Auditorium Course (171.101)</th>
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<tr>
<td>FCI Pre-test</td>
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<tr>
<td>Midterm 1</td>
<td>74.8%</td>
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<td>Midterm 2</td>
<td>67.4%</td>
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Table 1: Results of exams and diagnostic testing of students in the new SCALE-UP course in the main General Physics course taught in the auditorium using active-learning methods for fall 2013.
Another measure of student response to the active-learning course is how they “vote with their feet”, i.e., whether they choose to stay in the course and whether word-of-mouth encourages others to switch to it. In fall 2013, 47 students took SCALE-UP General Physics I. In the current spring 2014 semester, 59 students are registered for SCALE-UP General Physics II. The spring enrollments of the students who took the fall course break down as follows:

- Continuing with SCALE-UP course: 32
- Switching to lecture-based course: 11
- Switching to course for Physics majors: 2
- Not enrolled in Physics: 2

Thus, approximately 75% of the students (32/43) from the SCALE-UP course who are continuing with General Physics have opted to continue with this teaching format. In addition, 27 students have chosen SCALE-UP this spring after either taking the more conventional form of General Physics in the fall or placing out of it. We note that the SCALE-UP course and the lecture-based course are taught at different times, so students’ scheduling constraints rather than preference likely impacts some of these enrollment numbers.

As additional part of the assessment of the SCALE-UP course, Michael Reese from CER conducted a student self-assessment survey that evaluated gains in students’ perception of their knowledge and experience with the major concepts in the course and with other key educational goals, such as their ability to analyze information presented graphically or mathematically. The survey also asked the students to evaluate the helpfulness of various components of the course, such as the “tangibles” and other in-class activities, the textbook, TA and faculty instructor office hours, and homework assignments. As one example of the results of the survey, 84% of students found the use of class time to be helpful or very helpful in learning the material. A similar survey will be conducted in the second-semester of the course sequence in spring 2014, and we will continue to administer the surveys in future years, using the results from this academic year as a baseline as we seek to improve the courses.