LIGHTS, CAMERA, ACTING TRANSPORT!

THE EFFECTS OF A KINESTHETIC ACTIVITY AND A CURRICULUM REVISION ON STUDENT LEARNING GAINS AND RETENTION OF KEY CONCEPTS OF MEMBRANE TRANSPORT

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by

Susanne Ruth Gnagy

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LIGHTS, CAMERA, ACTING TRANSPORT!

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A Thesis

by

Susanne Ruth Gnagy

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Date

Department of Biological Sciences
Abstract

of

LIGHTS, CAMERA, ACTING TRANSPORT!

THE EFFECTS OF A KINESTHETIC ACTIVITY AND A CURRICULUM REVISION ON STUDENT LEARNING GAINS AND RETENTION OF KEY CONCEPTS OF MEMBRANE TRANSPORT

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Susanne Ruth Gnagy

Recent national reports have highlighted the importance of recruiting and retaining more college students from diverse backgrounds in the sciences. To this end, science educators have been tasked to critically evaluate their teaching methods in order to design curricula that are both effective and engaging for all students. This study used an action research design to (1) assess student learning from a role-play activity; (2) use the results of this assessment to revise the activity; and (3) evaluate the effectiveness of the revised curriculum. The activity was designed to teach students about membrane transport, and a pre-test, post-test, retention test instrument was used to assess student understanding of key concepts. In addition, student learning from the activity, and retention of these concepts over time, were compared to demographic and general academic characteristics to determine whether the activity was equally effective for all students.
Assessment of student learning from the activity in the Fall 2011 and Spring 2012 semesters (cohort 1) revealed that participation in the activity led to significant learning gains on the day of the activity (pre-test to post-test), and that after ten weeks, these learning gains were largely retained (pre-test to retention test). However, close evaluation of the assessment results revealed that students were not learning and retaining all concepts equally. In particular, students struggled to understand co-transport, and two common student misconceptions were identified. The activity was revised to address these difficulties, and to incorporate student suggestions from an open-ended survey question. The revised protocol was implemented in the Fall 2012 semester (cohort 2). Comparisons of student learning between cohorts revealed that the activity revisions resulted in non-significant improvements in overall student scores on the post- and retention tests, and significantly improved understanding of co-transport on the retention test.

Evaluation of the relationships between student learning and retention over time, and student demographic and academic characteristics, revealed that overall, this activity is an effective learning exercise for many different types of students. However, Caucasian and underrepresented minority (URM) students outperformed Asian students on the post-test, though not the retention test, indicating that this activity may be a less effective learning tool in the short term for the Asian students. In addition, there were small but significant correlations between students’ performance in lecture and students’ performance on the post- and retention tests.
This study demonstrates that curriculum assessment can be an effective way to evaluate a learning activity; it can be used to identify areas of student difficulty, and targeted revisions may then lead to improved learning in future iterations. Moreover, identifying factors that may influence student learning outcomes can be a way to design future curricula that are more effective for all students.

_______________________, Committee Chair
Kelly McDonald, Ph.D.

_______________________
Date
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Acknowledgements</th>
<th>viii</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Tables</td>
<td>xi</td>
</tr>
<tr>
<td>List of Figures</td>
<td>xii</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Preliminary research</td>
<td>4</td>
</tr>
<tr>
<td>Revising the activity</td>
<td>15</td>
</tr>
<tr>
<td>Evaluating patterns of student learning and retention</td>
<td>19</td>
</tr>
<tr>
<td>Objectives and hypotheses</td>
<td>21</td>
</tr>
<tr>
<td>METHODS</td>
<td>22</td>
</tr>
<tr>
<td>Activity protocol</td>
<td>22</td>
</tr>
<tr>
<td>Survey instruments and student consent form</td>
<td>22</td>
</tr>
<tr>
<td>Activity implementation and data collection</td>
<td>23</td>
</tr>
<tr>
<td>Analysis of cohort 2 data</td>
<td>24</td>
</tr>
<tr>
<td>Comparison of scores obtained before and after the revision</td>
<td>25</td>
</tr>
<tr>
<td>Evaluation of student understanding of co-transport</td>
<td>25</td>
</tr>
<tr>
<td>Student characteristics and student learning and retention over time</td>
<td>26</td>
</tr>
<tr>
<td>Institutional review board (IRB)</td>
<td>29</td>
</tr>
<tr>
<td>Evaluation of the survey instrument</td>
<td>29</td>
</tr>
<tr>
<td>RESULTS</td>
<td>31</td>
</tr>
<tr>
<td>Analysis of cohort 2 data</td>
<td>31</td>
</tr>
</tbody>
</table>
### LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Key concepts of membrane transport addressed by five content-based questions on the pre-, post- and retention tests</td>
<td>7</td>
</tr>
<tr>
<td>2.</td>
<td>Text of concept questions 4 and 5</td>
<td>13</td>
</tr>
<tr>
<td>3.</td>
<td>Relative frequencies of different student response patterns for the Fall 2011 and Spring 2012 semesters</td>
<td>16</td>
</tr>
<tr>
<td>4.</td>
<td>Percentages of students selecting the correct answer, the previously identified MCIA, and all other answers for questions 4 and 5 in cohorts 1 and 2</td>
<td>34</td>
</tr>
<tr>
<td>5.</td>
<td>Frequencies and relative frequencies of different student response patterns in cohorts 1 and 2</td>
<td>38</td>
</tr>
<tr>
<td>6.</td>
<td>Distributions of students from the Fall 2012 semester for demographic and academic performance variables</td>
<td>40</td>
</tr>
<tr>
<td>7.</td>
<td>Results of statistical analyses comparing student demographic and academic performance variables to: (1) pre-, post- and retention test scores; and (2) learning and retention pattern</td>
<td>41</td>
</tr>
<tr>
<td>8.</td>
<td>Students reporting confusion with the questions of the concept questionnaire</td>
<td>45</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figures</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Student scores (mean ± SD) from pre-, post- and retention tests for the Fall 2011 and Spring 2012 semesters (N = 174)</td>
<td>9</td>
</tr>
<tr>
<td>2. Percentages of correct answers obtained for each of the five concept questions for the Fall 2011 and Spring 2012 semesters</td>
<td>11</td>
</tr>
<tr>
<td>3. Percentages of students selecting each answer choice for questions 4 and 5 for the Fall 2011 and Spring 2012 semesters</td>
<td>14</td>
</tr>
<tr>
<td>4. Student scores (mean ± SD) from pre-, post- and retention tests for cohorts 1 (N = 174) and 2 (N = 77)</td>
<td>32</td>
</tr>
<tr>
<td>5. Percentages of students selecting the correct answer and the previously identified MCIA for questions 4 and 5 in cohorts 1 and 2</td>
<td>35</td>
</tr>
<tr>
<td>6. Percentages of students selecting each answer choice for question 5 in cohorts 1 and 2</td>
<td>37</td>
</tr>
<tr>
<td>7. Mean student scores obtained on the pre-, post- and retention tests for each retention pattern</td>
<td>43</td>
</tr>
</tbody>
</table>
INTRODUCTION

During the past two decades, there has been a growing movement within the scientific community advocating the use of rigorous scientific methodology and experimental techniques to assess the efficacy of various teaching styles and pedagogical strategies (AAAS, 2011; Handelsman et al., 2004). Instructors are beginning to use the scientific method to address educational questions: hypotheses are proposed, experiments designed, and results statistically evaluated to determine what is effective in the field of science education (Armbruster, Patel, Johnson, & Weiss, 2009; Freeman et al., 2007; Hake, 1998; Udovic, Morris, Dickman, Postlethwait, & Wetherwax, 2002). As a result, there is a growing body of literature to which science educators can turn to design curricula that are more effective and engaging (T. R. Anderson, 2007; Handelsman et al., 2004), thereby recruiting future scientists from an increasingly diverse student population, and cultivating in them the skills necessary to succeed (W. L. Anderson, Mitchell, & Osgood, 2005; Freeman, Haak, & Wenderoth, 2011; Freeman et al., 2007; Tanner & Allen, 2004, 2007).

One aspect of science education that has received considerable attention is the role of active learning in effective teaching (Armbruster et al., 2009; Fossey & Hancock, 2005; Freeman et al., 2007; Hake, 1998; Udovic et al., 2002). Active learning is any instructional strategy that directly and actively involves students in their own learning processes. Examples include in-class discussions, Socratic questioning, minute papers, using clicker questions, Think-Pair-Share, Peer-Led-Team-Learning, Problem-Based Learning, and kinesthetic hands-on and role-play exercises (Allen & Tanner, 2002;
Numerous studies have compared courses incorporating active learning strategies with courses using a more traditional, passive learning approach, and the research consistently indicates that active learning improves student performance (W. L. Anderson et al., 2005; Armbruster et al., 2009; Freeman et al., 2011; Freeman et al., 2007; Hake, 1998; Udovic et al., 2002).

In light of the highly reproducible and overwhelming support for active learning as a pedagogical tool, research focus has shifted in recent years; assessing the efficacy of active learning per se is no longer the central issue. We have moved into a second generation of science education research, and the questions are now in the details (S. Freeman, personal communication, July 2012). For example: “Do all types of active learning work equally well?” (Freeman et al., 2011); “Are all student populations affected equally by different instructional techniques?” (W. L. Anderson et al., 2005; Haak, HilleRisLambers, Pitre, & Freeman, 2011; Hogan, Bagley, Reubens, & Henshaw, 2012; Metz, 2008); or “How can we use the results of our assessments to further improve our curricula?” (Smith & Knight, 2012).

As our understanding of effective pedagogy in science continues to grow, we also face the challenges of identifying and implementing those techniques that have been shown to work. In fact, two key goals outlined in the American Association for the Advancement of Science (AAAS) report, “Vision and Change in Undergraduate Biology Education: A Call to Action” (2011), are (1) the development of a centralized, accessible repository for the growing body of pedagogical research and instructional tools,
something that science educators can use to develop curricula that will impact a broader student community; and (2) faculty development, teaching faculty to design curricula based on this research foundation and supporting them in these efforts (Holm, Carter, & Woodin, 2011).

To meet these goals, it is clear that instructors must become actively engaged in creating well-founded curricula based on the results of science education research; in evaluating the effectiveness of said curricula; and in disseminating their findings to the larger scientific community. To these ends, T. R. Anderson (2007) has advocated the use of action research, which he defines as “a cyclical process of implementing a curriculum intervention, collecting, and processing quantitative and qualitative student data, reflecting on the success of the intervention and, if necessary, modifying the intervention and reimplementing it until satisfied with the changes” (p. 467). In other words, curriculum reform should be a dynamic, scientific process, based on prior research and new hypotheses, the application of ideas, data collection and analyses, adjustments, and ultimately conclusions and new questions.

For this study, an action research design was used to: (1) evaluate the effectiveness of a curriculum activity that was developed as an active-learning exercise based on first-generation science education research; (2) reform the activity based on the results of this evaluation, i.e., implement “second-generation” research; and (3) evaluate the new activity and the effects of the changes on student learning outcomes.
Preliminary research

Activity overview. *Lights, Camera, Acting Transport!* is an active, highly
kinesthetic, role-play exercise that was first introduced into the curriculum of Bio 2:
Cells, Molecules and Genes at California State University, Sacramento in the Fall 2009
semester. Bio 2 is a required introductory course for all biology majors at this institution,
and this activity was designed in response to instructor observations that many students
struggle with the fundamental concepts of membrane transport (K. K. McDonald,
personal communication, July 2012). Incorporating a variety of instructional strategies
into a curriculum is a way to reach out to students with different learning styles, and to
promote diversity in the sciences (Tanner & Allen, 2004), and role-play is a type of
activity that will certainly appeal to kinesthetic learners (i.e., those who prefer tangible,
physical learning experiences). In addition, because it literally brings academic material
to life, and gives instructors and students immediate feedback, role-play has wide appeal
and is usually enjoyed by all (van Ments, 1999). Indeed, role-play has been previously
used in biology instruction to teach such concepts as glycolysis (Ross, Tronson, &
Ritchie, 2008) and protein synthesis (Sturges et al., 2009).

*Lights, Camera, Acting Transport!* is a three-act play in which students
representing molecules and ions attempt to enter the cell, and must find the best way in
(e.g., directly across the plasma membrane, or through a specialized transport protein or
pump). Other students, representing the components of the plasma membrane, must
determine whether or not each molecule can cross, and throughout the activity, students
must vocalize and justify their decisions. Act I explores simple and facilitated diffusion,
Act II features a Na⁺/K⁺ electrogenic pump (primary active transport), and Act III introduces co-transport (secondary active transport). To prepare for the activity, students are asked to read about membrane transport in their text and complete a pre-activity worksheet, and the entire play is performed during one of the course’s weekly 110-minute activity sessions.

**Study design.** On end-of-semester evaluations, students routinely reported that this activity was one of their favorite exercises of the semester. However, popularity does not necessarily translate to efficacy, and so in the Fall 2011 and Spring 2012 semesters, a pilot study was conducted to evaluate the effectiveness of this activity and its impact on student learning. A pre-test/post-test instrument (Sundberg, 2002) was used to assess student understanding of key concepts and student attitudes before and after participation in this activity. Pre-test/post-test instruments are widely-employed assessment tools, used to gauge both learning and attitudes (Baxter & Norman, 2011; Hake, 1998; Knight & Wood, 2005; Metz, 2008; Nazario, Burrowes, & Rodriguez, 2002; Reinfried, Aeschbacher, & Rottermann, 2012; Shoemaker, 2010; Smith & Knight, 2012; Udovic et al., 2002), and they have been used to evaluate other kinesthetic and role-play activities (Breckler & Yu, 2011; Sturges et al., 2009).

In this study, the pre- and post-tests were both administered to students on the day that they participated in the activity, at the beginning and end of the class session. In addition, a second post-test, the retention test, was administered ten weeks later to assess student retention of key concepts. In 2002, Trempy, Skinner, and Siebold observed that
students retained knowledge acquired through cooperative learning in their course “The World According to Microbes,” and in the Policy Forum “Scientific Teaching,” Handelsman et al. (2004) advocated increased research to examine student retention of learning gains. Since 2004, several studies have used a retention test in conjunction with a pre-test/post-test instrument to do just that (Breckler & Yu, 2011; Metz, 2008; Reinfried et al., 2012; Sturges et al., 2009). However, the timing of the retention test has ranged from less than one week to one year after the first post-test, which certainly allows for a considerable degree of variation in what one might consider retention. Stewart, Myers, and Culley (2010) have advocated waiting at least two months to assess retention, and the ten-week interval used in this study is in alignment with their recommendation.

The pre-test, post-test and retention test in this study each contained the same set of five multiple-choice content questions, designed to test student understanding of the basic concepts of membrane transport covered in the activity; the key concepts addressed by these questions are summarized in Table 1. Student responses were anonymous, but linked to allow comparison of individual learning gains and losses among the three tests, and students were not informed about the tests prior to the days of administration. The pre- and post-tests also contained several attitudinal prompts to assess student views about their own learning and about the activity, including two open-ended questions on the post-test asking for student feedback about the exercise; specifically, these questions gave students an opportunity to describe what they liked best, and least, about the activity.
Table 1: Key concepts of membrane transport addressed by five content-based questions on the pre-, post- and retention tests.

<table>
<thead>
<tr>
<th>Question</th>
<th>Key concept addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Identification of molecules that readily diffuse across the plasma membrane</td>
</tr>
<tr>
<td>2</td>
<td>Differences between facilitated diffusion and active transport</td>
</tr>
<tr>
<td>3</td>
<td>Primary function of the Na(^+)/K(^+) pump</td>
</tr>
<tr>
<td>4</td>
<td>Source of energy for co-transport</td>
</tr>
<tr>
<td>5</td>
<td>Direction of travel (with or against the gradient) for molecules and ions in co-transport</td>
</tr>
</tbody>
</table>
Evaluation of the activity. A total of eleven activity sections were evaluated in the two semesters of study, resulting in a sample size of 174 students who completed all three assessments. The average (mean ± SD) pre-test (40.8 ± 20.5%), post-test (66.1 ± 23.2%), and retention test (59.6 ± 22.6%) scores (Figure 1) were significantly different from one another (Friedman test: $\chi^2(2) = 152, p < 0.001; \alpha = 0.05$), and post-hoc Wilcoxon signed-rank tests showed that these differences were significant between each pair of scores (Pre-Post, $Z = -9.87, p < 0.001$; Pre-Ret, $Z = -7.91, p < 0.001$; Post-Ret, $Z = -4.17, p < 0.001; \alpha = 0.017$). In other words, students learned from this exercise, and although the average score did decline after ten weeks, it was still significantly higher than before the activity.

Although the initial pre- to post-test learning gains, which constituted a 62% improvement in the average score, could be ascribed directly to the membrane transport activity, this study was not designed to distinguish between retention attributable to this intervention and retention from some other source in the intervening weeks (e.g., reinforcement of concepts through lecture, lab or studying). However, in both semesters of this study, membrane transport was covered in lecture and lab in the same week as the activity, and these concepts were incorporated into an exam at the start of the following week. Thus, the only subsequent reinforcement would have been from individual study, or integration with other topics covered in the course, and given that only 26% of the initial learning gains were lost after ten weeks, it seems plausible to consider that this retention was due, at least in good part, to this activity.
Figure 1: Student scores (mean ± SD) from pre-, post- and retention tests for the Fall 2011 and Spring 2012 semesters (N = 174). Matching letters above error bars indicate that two groups are significantly different from one another.
In addition to this evaluation of the overall changes in student scores, the assessment data were examined in more detail to see whether there were any notable patterns or trends for the individual questions of the survey. A number of studies have utilized questionnaires, concept inventories and pre-test/post-test instruments to identify areas of student weakness in conceptual understanding, and also to identify common misconceptions held by a notable proportion of test takers (Galley, 2004; Metz, 2008; Nazario et al., 2002; Smith & Knight, 2012; Smith, Wood, & Knight, 2008). Not only is it useful to identify those questions that students are answering incorrectly, it can also be informative to examine the specific incorrect answers that students are selecting. Often, there may be a “most frequent incorrect answer” (Nazario et al., 2002), also referred to as a “most common incorrect answer” (Smith & Knight, 2012), and hereafter referred to as an MCIA. Smith and Knight (2012) define an MCIA as an incorrect answer selected by at least 20% of the students surveyed for a survey instrument with five possible answers for each question; in other words, it is an answer selected by a proportion of students that is larger than would be expected if students were selecting that answer at random. They further note that the identification of such misconceptions can give instructors an opportunity to adjust the curriculum in order to address these specific concepts more thoroughly (Smith & Knight, 2012).

To assess student performance on each of the five questions, the percentage of correct answers obtained for that question, out of the total number of student responses, was calculated for each survey (pre-, post-, retention) (Figure 2). For questions 1-3, students generally performed well: correct answers on the pre-test made up 49-59% of
Figure 2: Percentages of correct answers obtained for each of the five concept questions for the Fall 2011 and Spring 2012 semesters. Data are presented for each test (pre-, post- and retention).
the responses, and the percentages of correct answers on the retention test were higher (68-75%). However, the percentages of correct answers on questions 4 and 5 were considerably lower. Only 16-22% of students correctly answered these questions on the pre-test, and after ten weeks, the percentages of correct answers hovered just above 40%. Interestingly, both questions with which students struggled were about co-transport (Table 2).

To further clarify the nature of student misunderstandings on these low-scoring questions, the percentage of students selecting each possible multiple-choice answer for each question (4 and 5) was calculated. An MCIA for these questions, each with four possible answer choices, would be an answer selected by at least 25% of students. For each question, there was a single, clear MCIA that students were choosing in lieu of the correct answer (Figure 3). In question 4, students understood that co-transport is active, but struggled with the idea that it does not directly require ATP. Although the MCIA in question 4 was largely replaced by the correct answer immediately following the activity, this switch was temporary, and the MCIA returned after ten weeks. In question 5, students incorrectly believed that both molecules involved in co-transport move against their respective concentration gradients, and the correct answer was never selected by more than 43% of students. In both cases, the presence of the MCIA at levels similar to those of the correct answer after ten weeks indicates that these misconceptions were persistent. Students favored the MCIA over other answers, including the correct answer, and these misconceptions appear to be resistant to change.
Table 2: Text of concept questions 4 and 5.

<table>
<thead>
<tr>
<th>Question</th>
<th>Option A</th>
<th>Option B</th>
<th>Option C</th>
<th>Option D</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. The mechanism of co-transport…</td>
<td>is a type of active transport that requires energy in the form of ATP.</td>
<td>is a type of active transport that does NOT require energy in the form of ATP.</td>
<td>is a type of passive transport that requires energy in the form of ATP.</td>
<td>is a type of passive transport that does NOT require energy in the form of ATP.</td>
</tr>
<tr>
<td>5. A sodium-glucose co-transporter…</td>
<td>transports sodium only against its concentration gradient.</td>
<td>transports glucose only against its concentration gradient.</td>
<td>transports both sodium and glucose against their concentration gradients.</td>
<td>transports neither sodium nor glucose against their concentration gradients.</td>
</tr>
</tbody>
</table>
Figure 3: Percentages of students selecting each answer choice for questions 4 and 5 for the Fall 2011 and Spring 2012 semesters. Data are presented for each test (pre-, post- and retention).
In a final evaluation of overall student retention, the underlying patterns of student learning gains and losses over time were examined. In other words, although the “average pattern” of the data was one in which the lowest score (pre-test) was followed by the highest score (post-test) with a final score somewhere in the middle (retention test), it was possible that not all students exhibited this “LHM” pattern. In fact, only 41% of students had scores that conformed to this trend (Table 3). An additional 8% of students maintained their post-test scores on the retention test (LHH), and 26% showed continued improvement in scores after ten weeks (LMH). In contrast, 12% of students actually performed worse on the retention test than on the original pre-test, despite initial learning gains (MHL). Clearly, student retention is more complex than it may seem at first glance, and there could be factors besides time affecting both learning and retention that are important. These patterns may be linked, for example, to demographic variables, or to overall course or academic performance, data which were not collected under this strictly anonymous study design.

Revising the activity

Students showed significant learning gains and retention of basic membrane-transport concepts after participating in the *Lights, Camera, Acting Transport!* activity. However, they were not learning, or retaining, all of the concepts equally. In particular, the test scores highlight the difficulty that many students were having understanding and remembering the mechanisms of co-transport. In light of this finding, the activity protocol was examined, and in fact, there was a relative dearth of attention given to co-
Table 3: Relative frequencies of different student response patterns for the Fall 2011 and Spring 2012 semesters.

<table>
<thead>
<tr>
<th>Pattern †</th>
<th>Relative frequency ‡</th>
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</thead>
<tbody>
<tr>
<td>LHM</td>
<td>0.41</td>
</tr>
<tr>
<td>LMH</td>
<td>0.26</td>
</tr>
<tr>
<td>MHL</td>
<td>0.12</td>
</tr>
<tr>
<td>LHH</td>
<td>0.08</td>
</tr>
<tr>
<td>All other patterns (n=6)</td>
<td>0.13</td>
</tr>
</tbody>
</table>

† Patterns go from pre- to post- to retention test; L = lowest score, M = middle score, H = highest score.
‡ Proportion of students with a given pattern, out of all participants.
transport when compared to basic diffusion and primary active transport, in both the pre-activity worksheet and in the activity instructions. In addition, because co-transport is the subject of the third and final act of the play, it was possible that students were suffering from mental fatigue, or were overwhelmed by the sheer amount of information already covered.

According to the principles of backward design, when creating a curriculum, one should first determine the learning objectives and the assessments to be used, and then design a curriculum that will achieve the desired outcomes (Dirks, Wenderoth, & Withers, 2014; Senkevitch, Smith, Marbach-Ad, & Song, 2011; Wiggins & McTighe, 1998). In this case, the disjunct between the assessment and the activity design could have been responsible, at least in part, for the lower scores observed on the co-transport questions. This activity could then be improved by applying the backward design method. The activity protocol could be revised to more accurately reflect the desired learning outcomes, as indicated by the assessment instrument, giving more attention to the concepts of co-transport and specifically addressing the difficulties revealed by the MCIAs.

Student comments from the open-ended questions on the post-test were also examined to see whether the students themselves could provide insight into ways in which the activity could be improved. A number of students observed that they would have liked the opportunity to take notes; several also mentioned that they would benefit from more time with the concepts, while others advocated increased participation from everyone. Incorporating different types of active-learning exercises into the role-play
script would be a way to address these concerns, and would have the added advantage of providing the activity with more variety—variety to appeal to different learning styles (Tanner & Allen, 2004), and to divide the activity into smaller units, thereby maintaining or even revitalizing student interest in the subject matter.

One type of instructional strategy that is widely and effectively used in active-learning curricula is peer-based group learning (Allen & Tanner, 2005; W. L. Anderson et al., 2005; Eberlein et al., 2008; Farrell, Moog, & Spencer, 1999; Karge et al., 2011; Knight & Wood, 2005; Lasry, Mazur, & Watkins, 2008; Lyman, 1981; Senkevitch et al., 2011; Smith et al., 2009; Trempy et al., 2002). While this broad strategy can take many different forms (e.g., cooperative learning, problem-based learning, peer-led team learning), all types of group learning have in common some form of peer discussion that diversifies the curriculum and gives students a chance to explore ideas in a relatively safe setting. Moreover, peer discussion actually improves students’ conceptual understanding of course material (Smith et al., 2009). However, in addition to the benefits that can be derived from group learning, students can also benefit from having extended individual “think time” to process new information and develop answers to questions (Allen & Tanner, 2002), particularly those students who are reflective learners who prefer to process new material internally (Tanner & Allen, 2004).

Think-Pair-Share (Lyman, 1981) is a type of peer-based learning activity that provides students with opportunities for individual contemplation and group discussion, and student note-taking can be readily included in these exercises. In this technique, students are first given a question or problem, and asked to think about it on their own.
After an appropriate interval, students are asked to pair up with a fellow student (small groups can also be used), and discuss the idea together. Finally, the discussion is opened up to the room as a whole, and students are asked to share their ideas with the rest of the class. Think-Pair-Share activities can be, and have been, easily incorporated into larger lessons (Allen & Tanner, 2002; Armbruster et al., 2009; Freeman et al., 2011; Freeman et al., 2007; Karge et al., 2011), and could easily be included in the script of _Lights, Camera, Acting Transport!_ to provide students with more opportunities to contemplate and process the material covered in the play.

In sum, revising the activity to more accurately reflect desired learning outcomes (backward design) (Dirks et al., 2014; Senkevitch et al., 2011; Wiggins & McTighe, 1998); incorporating more active learning to appeal to different learning styles (e.g., active and reflective learners, kinesthetic and reading/writing learners) (Tanner & Allen, 2004); and focusing more attention on specific, identified misunderstandings (Galley, 2004; Nazario et al., 2002; Smith & Knight, 2012; Tanner & Allen, 2005; Udovic et al., 2002) could improve student test scores overall when compared to the former design, and specifically, could decrease the number of students struggling with the concepts of co-transport.

Evaluating patterns of student learning and retention

An additional direction for future research into student learning gains and retention that stems from this pilot study is the further examination of the aforementioned “patterns” of student learning and retention. The vast majority of studies using a pre-
test/post-test instrument have used two tests. In such a format, there are a limited number of outcomes—scores can improve, decline, or stay the same. However, adding in a third retention test increases the number of outcomes that are possible (Table 3), and students in this pilot study demonstrated very different patterns of learning and retention over time. Attempting to understand factors that may be correlated with, or even driving, these different patterns could identify student populations that may be having a more difficult time learning and retaining subject matter. Identifying demographic or academic risk factors could eventually lead to teaching strategies that have been adapted to reach a broader audience. Factors that may influence student performance include GPA (Freeman et al., 2007), gender (Metz, 2008), and minority status (Hogan et al., 2012), and a growing number of studies and reports have emphasized the importance of designing curricula that will increase student diversity in the sciences (e.g., W. L. Anderson et al., 2005; Freeman et al., 2011; Freeman et al., 2007; PCAST, 2012). It is also possible that the observed learning and retention patterns are correlated with overall course performance such that the students who learned and/or retained less performed poorly in the course overall, and vice versa. Collecting demographic and academic performance data, and comparing these data to students’ learning and retention patterns, could reveal novel connections and improve our understanding of student learning and retention of knowledge in the sciences.
Objectives and hypotheses

The first objective of the current study was to improve student understanding of membrane transport by revising the Lights, Camera, Acting Transport! activity. These revisions were based on the principles of backward design, addressed areas of student difficulty regarding co-transport identified in the pilot study, and incorporated additional learning activities into the curriculum so that the activity would appeal to students with a greater variety of learning styles. Specifically, two hypotheses were tested:

- **Hypothesis 1.** The revised activity protocol would result in an improvement in overall student scores on the post-test and retention test when compared to overall student scores obtained before the revision.

- **Hypothesis 2.** The revised activity protocol would result in improved student understanding of the concepts of co-transport when compared to student understanding of co-transport as measured in the pilot study, before the activity revision.

The second objective of the current study was to compare temporal patterns of student learning and retention to demographic and academic variables, including gender, race, GPA, and overall course performance, to determine whether student characteristics affect student learning and understanding over time.
METHODS

Activity protocol

The *Lights, Camera, Acting Transport!* activity protocol was revised so that the key concepts covered in the pre-activity worksheet (Appendix A) and throughout the exercise (activity instructions, Appendix B) were better aligned with the key concepts assessed by the pre-, post- and retention test instruments (Appendix C). Specifically, more attention was devoted to co-transport, and to improving students’ understanding of the electrochemical gradients that define this type of active transport, because of the difficulty students were having understanding these concepts in the pilot study. In addition, the previously-identified misconceptions about co-transport were explicitly addressed as a part of the new protocol. Think-Pair-Share exercises were incorporated into all three acts of the play to provide students with time for reflection, note-taking and peer discussion, and the new protocol also included increased use of the board by students and instructors in order to visually clarify and reinforce the material covered in each act.

Survey instruments and student consent form

The pre-test, post-test, and retention test instruments used in the Fall 2012 semester (cohort 2) contained the same five multiple-choice content questions as the Fall 2011 and Spring 2012 semesters (cohort 1) (Appendix C). As before, these questions were identical on all three tests (pre-, post-, and retention), albeit with the order of answers rearranged from one administration to the next. A demographic survey
(Appendix D) was created to collect self-reported data on gender, ethnicity, GPA, parents’ education, extracurricular employment, traditional vs. non-traditional status, and academic level, and a student consent form (Appendix E) was generated to allow for the use of all survey data, and for access to students’ exam scores from the lecture portion of Bio 2.

Activity implementation and data collection

The revised activity was conducted during the fourth week of instruction of the Fall 2012 semester in each of four 110-minute activity sections for Bio 2. To standardize the activity protocol as much as possible among these sections, the two instructors of record (K. K. McDonald and S. R. Gnagy) followed a specific set of instructor guidelines (Appendix F) with an instructor checklist for each section, and used specific, detailed activity instructions (Appendix B) during the activity. Prior to the activity, students were asked to read about membrane transport in their text, and to fill out the pre-activity worksheet to prepare for the upcoming role-play exercise.

On the day of the activity, the instructors first collected the pre-activity worksheet, and then administered the pre-test. Once students had completed the pre-test, the instructors reviewed the answers to the pre-activity worksheet as a class, and conducted the revised activity. At the end of the activity, students were encouraged to ask any final questions, and then the post-test was administered. Once students had completed the post-test, the answers to the test questions were reviewed as a class. The pre-activity worksheet was not returned to students in case differential reviews of this
worksheet by students in the weeks following the activity, and whether their copies contained correct or incorrect answers, might influence future student performance on the retention test.

Ten weeks later, the retention test and demographic survey were administered, and the consent form was distributed to students to sign. As in the pilot study, students were not informed in advance of any of the surveys. In addition, for all of these surveys, students were informed that their answers would be anonymous and that putting their names on the surveys was only necessary to link data among the survey instruments and the exam scores, at which point names would be removed and replaced by anonymous study IDs. For the demographic survey, students were further informed that they could choose not to answer any of the questions for any reason. Finally, students were informed that all of these data would be securely stored, and not accessed until the semester had ended and final course grades had been submitted.

After final grades for the Fall 2012 semester were submitted, the student consent forms were reviewed and any students who did not consent to participate (N = 2) or did not sign a consent form (N = 5) were immediately removed from the study. Survey data were then linked, anonymized and entered, and data from lecture exams were accessed, anonymized and linked to the survey data.

Analysis of cohort 2 data

Student scores from the five concept questions on each survey (pre-, post- and retention) from the Fall 2012 semester (cohort 2) were calculated, and learning gains and
losses among the three tests were assessed using a Friedman test, and when appropriate, post-hoc Wilcoxon signed-rank tests with a Bonferroni correction. These within-cohort calculations and assessments were identical to those that were conducted during the pilot study, using data from the Fall 2011 and Spring 2012 semesters (cohort 1).

Comparison of scores obtained before and after the revision

To evaluate whether the revised activity protocol was resulting in an overall improvement in student understanding when compared to the original activity protocol, student scores on the concept questionnaire obtained from students using the revised activity (cohort 2) were compared to student scores on the concept questionnaire obtained from students who participated in the activity before the revision (cohort 1). Specifically, three Mann-Whitney tests were used to compare cohorts 1 and 2 using the dependent variables of pre-test scores, post-test scores, and retention test scores.

Evaluation of student understanding of co-transport

To evaluate student understanding of co-transport (i.e., questions 4 and 5) from the revised protocol, the percentages of students selecting each answer to each question were calculated, and compared to the data obtained before the curriculum revision. In particular, these data were examined to compare the percentages of students who chose the correct answer and the previously identified MCIA for each of these questions in each cohort. To compare the numbers of students who correctly answered questions 4 and 5 before and after the activity revision, a series of three chi-square tests of association were
used for each question. Specifically, for each question, the two cohorts were compared for each of the three tests (pre-test, cohorts 1 vs. 2; post-test, cohorts 1 vs. 2; and retention test, cohorts 1 vs. 2). For the MCIAs, if the percentage of students choosing the MCIA fell below 25% for any test, that misconception was considered to be overcome for that test, since an MCIA in this study would be, by definition, an incorrect answer selected by at least 25% of students. In addition, chi-square tests of association were used to determine whether there were any significant differences in the numbers of students choosing each MCIA on each test for each question before, and after, the curriculum revision.

Student characteristics and student learning and retention over time

To examine the relationships between temporal patterns of learning and retention, and student demographics and academic performance, the retention pattern (e.g., LHM, LMH) for each student from the Fall 2012 semester (cohort 2) was determined, and the frequency and relative frequency of occurrence for each pattern were calculated, as was done in the pilot study (cohort 1). In addition, to determine whether the different patterns occurred with similar relative frequencies in both cohorts, chi-square goodness of fit tests were used to compare these two frequencies of occurrence (cohort 1 and cohort 2) for each pattern that occurred with sufficient numbers to use this statistical test.

Student responses for each of the categorical demographic variables gender, ethnicity, employment, traditional status, parents’ education and class level were tallied, and the percentages of students choosing each possible response for each variable were
calculated as the number of students choosing a response divided by the total number of student responses to the associated question. For ethnicity, the summary response category URM was created to include all students who would be considered underrepresented minorities (Hispanic, African-American, Native American or Pacific Islander) because URMs constitute a group of particular interest in science education research (Freeman et al., 2007), and because the individual numbers of students of each of these ethnicities were relatively small. It is this summary variable, rather than the individual ethnic groups from which it was derived, that was used in statistical comparisons for ethnicity. In addition, although students had the option to report multiple ethnicities (N = 5), only those students who reported a single ethnic affiliation were used for analyses. Self-reported data from the demographic survey for the continuous variable GPA were recorded with no further modification.

To create a variable that would represent student academic performance in the lecture component of the course, a summary variable, exam score, was calculated for each student from the lecture exam data. Two different instructors taught the lecture portion of this course in the Fall 2012 semester, and each had a slightly different exam structure in which the number of exams and the number of points possible per exam varied between sections. Therefore, to create a composite variable that would be consistent between sections and representative of each student’s performance, each exam score in each section was converted to a percentage in order to weight all exams equally, and the exam average for each student in a given section was then calculated out of all possible exams in that section.
Although a chi-square test of association would be an appropriate choice to statistically compare learning and retention pattern, a categorical variable, to each of the categorical demographic variables, preliminary examination of the data revealed that the sample size and distribution of data was not going to be sufficient to meet a key assumption of the chi-square test for any of these variables, namely that the expected count values for this test must be at least five. In light of this limitation, raw test scores from the pre-, post- and retention tests were used as a proxy for the learning and retention patterns as an alternate measure of student understanding of the concepts of membrane transport over time. A series of Mann-Whitney tests for the bivariate variables gender and traditional status, and Kruskal-Wallis tests (and post-hoc Mann-Whitney tests with a Bonferroni correction when appropriate) for all other categorical demographic variables, were used to compare each of the categorical demographic variables to students’ scores on each of the three concept questionnaires (pre-test, post-test, retention test). For the continuous variables GPA and exam score, these academic performance variables were compared to both the categorical learning and retention patterns, using Kruskal-Wallis tests, and to student scores on the pre-, post- and retention tests using Spearman rank correlations.

Finally, since the patterns of student learning and retention are derived by comparing the relative levels of each students’ scores on the pre-, post- and retention tests, it is possible that the variability in these patterns is not being driven by some intrinsic student characteristic or characteristics, but is actually an artifact of the absolute levels of students’ scores on each of these three tests. In other words, it is possible that
students who have very low pre-test scores are more likely to have patterns that begin with an “L,” students with very high post-test scores are more likely to have patterns with an “H” in the middle, and so forth. To examine this possibility, that the absolute levels of student scores are influencing the observed variability in student learning and retention patterns, the mean student score obtained on each test (pre-, post- and retention) was calculated for each subgroup of students with each pattern. These mean values were derived using data from all three semesters of study, and were graphed for all of the patterns to visually assess this possible relationship between test scores and patterns.

Excel (Microsoft Excel for Mac 2011, Version 14.1.2) and SPSS (IBM SPSS Statistics, Version 19) were used for all data management and analyses.

Institutional review board (IRB)

The research conducted in the Fall 2011 and Spring 2012 semesters was approved as Exempt under the CSUS IRB protocol #11-12-116. The research conducted in the Fall 2012 semester was approved as Exempt under the CSUS IRB protocol #12-13-055.

Evaluation of the survey instrument

The assessment instrument used in this study was created to evaluate a single learning activity for a single course. As such, its primary purpose was to provide feedback to the instructors of this course, and the survey instrument was not designed and evaluated with the same rigor as is used when constructing concept inventories intended for widespread use (e.g., Garvin-Doxas & Klymkowsky, 2008; Smith et al., 2008).
However, to examine the possibility that the questions on the survey might themselves in some way be confounding student responses, an open-ended survey (Appendix G) was administered to students in the Fall 2012 semester to find out whether the wording of any questions was confusing, whether any questions seemed to lack an appropriate answer, or whether any questions caused students to incorrectly answer a question for which they understood the underlying concept.

This survey was administered to students in the week following the role-play exercise (i.e., week 5), and students were able to view the post-test instrument while completing the survey to help them remember the details of each question, although the correct answers were not discussed or highlighted in any way at this time. Student responses were reviewed by both activity instructors (S. G. and K. M.), and any surveys with student comments that indicated confusion or difficulty with the wording of any question were noted. For each of these surveys, the question that was causing confusion was recorded along with the reason for the confusion, and these surveys were cross-referenced with the students’ actual answers on the post-test to determine whether this confusion actually resulted in incorrect student responses.
RESULTS

Analysis of cohort 2 data

A total of 77 students from the Fall 2012 semester (cohort 2) completed all four surveys (pre-test, post-test, retention test and demographic survey) and gave their consent to participate in this study, out of 89 students enrolled in the course. Student scores (mean ± SD) for cohort 2 on the pre-test (41.7 ± 21.6%), post-test (70.1 ± 21.4%) and retention test (64.6 ± 21.1%) were significantly different from one another (Friedman test: χ²(2) = 68.2, p < 0.001; α = 0.05). Additionally, there were significant improvements between the pre- and post-tests (Z = -6.69, p < 0.001; α = 0.017) and between the pre- and retention tests (Z = -6.00, p < 0.001, α = 0.017); however, the observed decline in student scores between the post-test and the retention test was not significant (Z = -2.28, p = 0.023; α = 0.017) (Figure 4).

Comparison of scores obtained before and after the revision

For all three pairs of tests (pre-test, cohorts 1 and 2; post-test, cohorts 1 and 2; retention test, cohorts 1 and 2), the mean student scores obtained from the revised curriculum (cohort 2) were higher than the mean student scores before the revision (cohort 1) (Figure 4). However, none of these differences was significant (Mann-Whitney tests: Pre-test, U = 6554, p = 0.78; Post-test, U = 5986, p = 0.18; Retention test, U = 5859, p = 0.11; α = 0.05).
Figure 4: Student scores (mean ± SD) from pre-, post- and retention tests for cohorts 1 (N = 174) and 2 (N = 77). Matching letters above error bars indicate that two groups are significantly different from one another.
Evaluation of student understanding of co-transport

The percentages of students selecting each answer choice for each of the co-transport questions (questions 4 and 5) on each test (pre-, post- and retention) were calculated for students using the revised curriculum, as was done in the pilot study; these data are summarized in Table 4. Both of the MCIs identified previously, before the curriculum revision, were still present after the revision; however, none of the other incorrect answer choices was selected by more than 25% of students on any test.

For question 4, the percentages of students choosing the correct answer from each cohort were similar on both the pre- and post-tests (Table 4, Figure 5). However, on the retention test, a significantly higher percentage of students selected the correct answer following the curriculum revision (57.1%) than before the revision (42.0%) ($\chi^2(1) = 4.95$, $p = 0.026; \alpha = 0.05$). In other words, although there was still a decline from the post-test to the retention test in the percentage of students selecting the correct answer, this decline was much less pronounced with the revised curriculum. The MCIA for question 4 was actually selected by a higher percentage of students in the post-revision cohort on both the pre- and post-tests. However, these between-cohort differences were not significant, and the MCIA was still successfully overcome on the post-test (i.e., selected by <25% of students) in the post-revision group, as was seen in the original study. Moreover, while this MCIA resurfaced on the retention test in the first cohort, where it was selected by 36.2% of students, the percentage of students choosing this answer stayed below 25%, at 23.4%, in the second cohort, and this difference was significant ($\chi^2(1) = 4.02$, $p = 0.045; \alpha = 0.05$).
Table 4: Percentages of students selecting the correct answer, the previously identified MCIA, and all other answers for questions 4 and 5 in cohorts 1 and 2. Data are presented for each test (pre-, post- and retention).

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>Post-test</th>
<th>Retention test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Correct</td>
<td>MCIA</td>
<td>Other†</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cohort</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>21.8%</td>
<td>56.9%</td>
<td>21.3%</td>
</tr>
<tr>
<td>2</td>
<td>16.9%</td>
<td>67.5%</td>
<td>15.6%</td>
</tr>
<tr>
<td></td>
<td>0.81</td>
<td>2.52</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>0.37</td>
<td>0.11</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cohort</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>16.1%</td>
<td>66.7%</td>
<td>17.2%</td>
</tr>
<tr>
<td>2</td>
<td>20.8%</td>
<td>49.4%</td>
<td>29.9%</td>
</tr>
<tr>
<td></td>
<td>0.81</td>
<td>6.75</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>0.37</td>
<td>0.009**</td>
<td>N/A</td>
</tr>
</tbody>
</table>

† Includes students who chose either of two other multiple-choice options, as well as any students who did not answer the question. ‡ Denotes an MCIA that was overcome (i.e., selected by <25% of students). * Denotes significance, $p < 0.05$. ** Denotes significance, $p < 0.01$. 
Figure 5: Percentages of students selecting the correct answer and the previously identified MCIA for questions 4 and 5 in cohorts 1 and 2. Data are presented for each test (pre-, post- and retention). * Denotes a significant difference between cohorts, $p < 0.05$. ** Denotes a significant difference between cohorts, $p < 0.01$. 
For question 5, although the correct answer was chosen by a higher percentage of students in the post-revision group for each of the three tests, none of these differences was significant (Table 4, Figure 5), and for all of these tests, the correct answer was only selected by, at most, half of the students (50.6%, post-test, cohort 2). The MCIA was never overcome for this question in either cohort, although the percentages of students choosing the MCIA were lower in the second cohort for all three tests. This reduction was highly significant on the pre-test, dropping from 66.7% of students in the first cohort to 49.4% of students in the cohort that used the revised curriculum with the revised pre-activity worksheet \( \chi^2(1) = 6.75, p = 0.009; \alpha = 0.05 \). However, this pre-test reduction was not accompanied by a comparable increase in the percentage of students choosing the correct answer; rather, one of the other incorrect answers (that co-transport moves \( \text{Na}^+ \) against its concentration gradient) was selected by a higher percentage of students in the second cohort than in the first cohort (Figure 6). While this alternate misconception was never selected by more than 22% of students on any test, and was thus never classified as an MCIA, this answer was also selected by approximately 20% of students on the retention test in both cohorts (Figure 6), making this another common incorrect answer that students were selecting in lieu of the correct response.

Student characteristics and student learning and retention over time

The learning and retention pattern for each student’s set of scores (pre-, post- and retention tests), as well as the number of students with each pattern and the relative frequency of each pattern, were determined for the Fall 2012 cohort (Table 5). When
Figure 6: Percentages of students selecting each answer choice for question 5 in cohorts 1 and 2. Data are presented for each test (pre-, post- and retention). * Denotes a significant difference between cohorts, $p < 0.01$. 
Table 5: Frequencies and relative frequencies of different student response patterns in cohorts 1 and 2.

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Frequency</th>
<th></th>
<th>Relative frequency‡</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cohort 1</td>
<td>Cohort 2</td>
<td>Total</td>
<td>Cohort 1</td>
<td>Cohort 2</td>
<td>Total</td>
</tr>
<tr>
<td>LHM</td>
<td>71</td>
<td>30</td>
<td>101</td>
<td>0.41</td>
<td>0.39</td>
<td>0.40</td>
</tr>
<tr>
<td>LMH</td>
<td>46</td>
<td>15</td>
<td>61</td>
<td>0.26</td>
<td>0.19</td>
<td>0.24</td>
</tr>
<tr>
<td>MHL</td>
<td>21</td>
<td>7</td>
<td>28</td>
<td>0.12</td>
<td>0.09</td>
<td>0.11</td>
</tr>
<tr>
<td>LHH</td>
<td>14</td>
<td>10</td>
<td>24</td>
<td>0.08</td>
<td>0.13</td>
<td>0.10</td>
</tr>
<tr>
<td>LHL</td>
<td>6</td>
<td>5</td>
<td>11</td>
<td>0.03</td>
<td>0.06</td>
<td>0.04</td>
</tr>
<tr>
<td>MLH</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>0.03</td>
<td>0.06</td>
<td>0.04</td>
</tr>
<tr>
<td>HML</td>
<td>7</td>
<td>2</td>
<td>9</td>
<td>0.04</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>LLH</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>0.01</td>
<td>0.03</td>
<td>0.01</td>
</tr>
<tr>
<td>HLL</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>HLM</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0.01</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>Total</td>
<td>174</td>
<td>77</td>
<td>251</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

† Patterns go from pre- to post- to retention test; L = lowest score, M = middle score, and H = highest score. ‡ Proportion of students with a given pattern, out of all participants.
these data were compared to the data obtained from the pilot study, the relative frequencies of the different patterns were similar between the two groups; approximately 40% of students in each group had the most common pattern (LHM), and the four most frequently observed patterns were the same (LHM, LMH, MHL and LHH), accounting for at least 80% of students in each cohort. In addition, these four most common patterns were also those that occurred in sufficient numbers to allow for between-cohort statistical comparisons of each pattern’s frequencies of occurrence: the two cohorts were not significantly different from each other for any of these patterns (LHM, $\chi^2(1) = 0.047, p = 0.83$; LMH, $\chi^2(1) = 1.22, p = 0.27$; MHL, $\chi^2(1) = 0.66, p = 0.42$; LHH, $\chi^2(1) = 1.82, p = 0.18; \alpha = 0.05$).

The demographic characteristics of, and academic performance data for, students in the Fall 2012 semester were calculated and summarized (Table 6), and the statistical analyses between these data and the variables pre-test score, post-test score, retention test score and learning and retention pattern were carried out (Table 7). Overall, there appears to be little association between these demographic and general academic variables, and student performance on the three tests assessing student understanding of membrane transport. However, there was a significant relationship between ethnicity and post-test score (Kruskal-Wallis test: $\chi^2(2) = 10.5, p = 0.005, \alpha = 0.05$). Post-hoc Mann-Whitney tests showed that this significance resulted from differences in scores between Asian (N = 27; mean ± SD = 58.7 ± 19.0%) and Caucasian (N = 28; mean ± SD = 75.3 ± 22.3%) students (Mann-Whitney test: $U = 210, p = 0.004, \alpha = 0.017$), as well as differences between Asian and URM (N = 16; mean ± SD = 75.2 ± 15.3%) students (Mann-Whitney
Table 6: Distributions of students from the Fall 2012 semester for demographic and academic performance variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Number†</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>41</td>
<td>53.2</td>
</tr>
<tr>
<td>Female</td>
<td>36</td>
<td>46.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>77</td>
<td>100</td>
</tr>
<tr>
<td>Ethnicity‡</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asian</td>
<td>27</td>
<td>38.0</td>
</tr>
<tr>
<td>Caucasian, Non-Hispanic</td>
<td>28</td>
<td>39.4</td>
</tr>
<tr>
<td>URM</td>
<td>16</td>
<td>22.5</td>
</tr>
<tr>
<td>Hispanic</td>
<td>9</td>
<td>12.7</td>
</tr>
<tr>
<td>African-American</td>
<td>1</td>
<td>1.41</td>
</tr>
<tr>
<td>Native American / Pacific Islander</td>
<td>6</td>
<td>8.45</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>71</td>
<td>100</td>
</tr>
<tr>
<td>Employment (h/wk)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 10</td>
<td>21</td>
<td>41.2</td>
</tr>
<tr>
<td>11-20</td>
<td>16</td>
<td>31.4</td>
</tr>
<tr>
<td>21-30</td>
<td>11</td>
<td>21.6</td>
</tr>
<tr>
<td>30</td>
<td>3</td>
<td>5.88</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>51</td>
<td>100</td>
</tr>
<tr>
<td>Traditional</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>58</td>
<td>80.6</td>
</tr>
<tr>
<td>No</td>
<td>14</td>
<td>19.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>72</td>
<td>100</td>
</tr>
<tr>
<td>Parents’ education§</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; High school</td>
<td>6</td>
<td>7.89</td>
</tr>
<tr>
<td>High school / GED</td>
<td>20</td>
<td>26.3</td>
</tr>
<tr>
<td>Associate’s / Trade</td>
<td>15</td>
<td>19.7</td>
</tr>
<tr>
<td>Bachelor’s</td>
<td>25</td>
<td>32.9</td>
</tr>
<tr>
<td>Master’s</td>
<td>5</td>
<td>6.58</td>
</tr>
<tr>
<td>Terminal</td>
<td>5</td>
<td>6.58</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>76</td>
<td>100</td>
</tr>
<tr>
<td>Class level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freshman</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>Sophomore</td>
<td>11</td>
<td>14.7</td>
</tr>
<tr>
<td>Junior</td>
<td>35</td>
<td>46.7</td>
</tr>
<tr>
<td>Senior</td>
<td>29</td>
<td>38.7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>75</td>
<td>100</td>
</tr>
<tr>
<td>GPA^</td>
<td>Range: 2.1-3.9</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>64</td>
<td>100</td>
</tr>
<tr>
<td>Exam score∞ (%)</td>
<td>Range: 54.5-95.6</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>76</td>
<td>100</td>
</tr>
</tbody>
</table>

† Excludes data from students who chose not to respond to a given question. ‡ URM = underrepresented minority. § Highest level achieved by either parent. △ Self-reported; continuous variable, range shown. ∞ Average of all lecture exams; excludes student who withdrew; continuous variable, range shown.
Table 7: Results of statistical analyses comparing student demographic and academic performance variables to:

(1) pre-, post- and retention test scores; and (2) learning and retention pattern. Data are from the Fall 2012 semester.

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Statistical test</th>
<th>Statistic</th>
<th>p-value</th>
<th>Statistic</th>
<th>p-value</th>
<th>Statistic</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Pre-test</td>
<td></td>
<td>Post-test</td>
<td></td>
<td>Retention test</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td>77</td>
<td>Mann-Whitney</td>
<td>$U = 662$</td>
<td>0.44</td>
<td>$U = 667$</td>
<td>0.46</td>
<td>$U = 656$</td>
<td>0.40</td>
</tr>
<tr>
<td>Ethnicity</td>
<td>71</td>
<td>Kruskal-Wallis</td>
<td>$\chi^2(2) = 0.71$</td>
<td>0.70</td>
<td>$\chi^2(2) = 10.5$</td>
<td>0.005**</td>
<td>$\chi^2(2) = 3.37$</td>
<td>0.19</td>
</tr>
<tr>
<td>Employment</td>
<td>51</td>
<td>Kruskal-Wallis</td>
<td>$\chi^2(3) = 2.79$</td>
<td>0.42</td>
<td>$\chi^2(3) = 3.59$</td>
<td>0.31</td>
<td>$\chi^2(3) = 0.99$</td>
<td>0.80</td>
</tr>
<tr>
<td>Traditional</td>
<td>72</td>
<td>Mann-Whitney</td>
<td>$U = 374$</td>
<td>0.65</td>
<td>$U = 332$</td>
<td>0.29</td>
<td>$U = 402$</td>
<td>0.96</td>
</tr>
<tr>
<td>Parents’ education</td>
<td>76</td>
<td>Kruskal-Wallis</td>
<td>$\chi^2(5) = 0.84$</td>
<td>0.97</td>
<td>$\chi^2(5) = 7.94$</td>
<td>0.16</td>
<td>$\chi^2(5) = 3.95$</td>
<td>0.56</td>
</tr>
<tr>
<td>Class level</td>
<td>75</td>
<td>Kruskal-Wallis</td>
<td>$\chi^2(2) = 0.33$</td>
<td>0.85</td>
<td>$\chi^2(2) = 1.09$</td>
<td>0.58</td>
<td>$\chi^2(2) = 0.21$</td>
<td>0.90</td>
</tr>
<tr>
<td>GPA</td>
<td>64</td>
<td>Spearman</td>
<td>$\rho = 0.13$</td>
<td>0.31</td>
<td>$\rho = 0.12$</td>
<td>0.37</td>
<td>$\rho = 0.11$</td>
<td>0.39</td>
</tr>
<tr>
<td>Exam score</td>
<td>76</td>
<td>Spearman</td>
<td>$\rho = 0.17$</td>
<td>0.15</td>
<td>$\rho = 0.26$</td>
<td>0.023*</td>
<td>$\rho = 0.33$</td>
<td>0.003**</td>
</tr>
</tbody>
</table>

Learning and retention pattern

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Statistical test</th>
<th>Statistic</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPA</td>
<td>64</td>
<td>Kruskal-Wallis</td>
<td>$\chi^2(7) = 2.58$</td>
<td>0.92</td>
</tr>
<tr>
<td>Exam score</td>
<td>76</td>
<td>Kruskal-Wallis</td>
<td>$\chi^2(8) = 6.43$</td>
<td>0.60</td>
</tr>
</tbody>
</table>

* Denotes significance, $p < 0.05$. ** Denotes significance, $p < 0.01$. 
test: $U = 114, p = 0.010, \alpha = 0.017$). In addition to these differences among ethnicities in post-test scores, Spearman rank correlations showed small, but significant, positive correlations between students’ lecture exam scores, and both the post- ($\rho = 0.26, p = 0.023$) and retention ($\rho = 0.33, p = 0.003$) test scores.

When the mean test scores obtained by students with each learning and retention pattern were calculated and visually compared (Figure 7), a trend emerged in which the relative levels of these scores (i.e., higher or lower means on each test) appeared to be very much related to the patterns themselves. For example, the five patterns that began with an “L” all exhibited lower average scores on the pre-test than any of the other patterns, and the four patterns with an “H” in the middle had the four highest average scores on the post-test.

Evaluation of the survey instrument

The student evaluation of the concept questionnaire was completed by 68 of the 77 students who participated in this study in the Fall 2012 semester. Seven of these students (10%) provided comments describing some degree of confusion that resulted from the phrasing of the questions. Students flagged three different questions, and no student had difficulty with more than one question. Two students expressed confusion regarding question 1, which had seven variables for students to assess. One of these two students did not perform well on this question, and responded correctly to only two of seven choices, while the reported confusion appears not to have been detrimental to the other student who chose six of seven correct responses. Three students reported
Figure 7: Mean student scores obtained on the pre-, post- and retention tests for each retention pattern. Data are combined from three semesters of study (Fall 2011, Spring 2012, Fall 2012).
confusion for question 2, but only one answered this question incorrectly, and two students were confused by question 5, but again, only one student answered this question incorrectly. These results are summarized in Table 8.
Table 8: Students reporting confusion with the questions of the concept questionnaire. Responses are categorized by survey question, and percentages are out of all subjects who completed the evaluation (N = 68).

<table>
<thead>
<tr>
<th>Question</th>
<th>Students with comments</th>
<th>Adversely affected students†</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>%</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>2.94</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>4.41</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>2.94</td>
</tr>
<tr>
<td>Total</td>
<td>7</td>
<td>10.3</td>
</tr>
</tbody>
</table>

† Out of students who had comments; see text for explanation.
DISCUSSION

The President’s Council of Advisors on Science and Technology (PCAST) (PCAST, 2012), the American Association for the Advancement of Science (AAAS) (AAAS, 2011), Nobel Prize recipient and science educator Carl Wieman (Wieman, 2007; Wieman & Perkins, 2005), and numerous other scientists and science educators have highlighted the growing importance of critically examining the ways in which we teach science in order to recruit and retain more students in the sciences, and to create a society that is, in general, more scientifically literate. In the 21st century, technological advances are a central aspect of everyday life, and we face global challenges such as climate change, for which we will need a larger, more diverse population of scientists and a more scientifically-educated populace to supplement the workforce and to guide policy and action (PCAST, 2012; Wieman, 2007; Wieman & Perkins, 2005). The 2012 PCAST report (PCAST, 2012) points out that we will need one million more new scientists in the next ten years, in addition to the numbers of new scientists that can be anticipated to join the workforce based on current trends and projections, in order to keep up with the anticipated demand for workers in science- and technology-related fields.

On average, only 40% of students who declare science majors when they begin post-secondary education actually obtain a science degree; therefore, focusing efforts on retention of students in the sciences would be an effective way to generate these additional numbers. In addition, while the majority of college students today are women and minorities, these students are less likely to complete degrees in the sciences than are white men (PCAST, 2012). Among the reasons students cite for leaving the sciences are
introductory courses that are uninteresting, and an academic environment that is unwelcoming (Gates & Mirkin, 2012; PCAST, 2012); therefore, improving the quality of introductory science courses to make them more effective and engaging, and more appealing to a diverse student body, is a way to increase retention of students in the sciences (PCAST, 2012). To do this, the PCAST report advocates the use of teaching methods that have been shown empirically to improve student learning, and specifically endorses active learning based on the large and varied body of research demonstrating the increased efficacy of these types of pedagogical strategies when compared to traditional lecture formats (PCAST, 2012). Therefore, designing active-learning exercises for the introductory biology classroom and critically evaluating the effectiveness of such exercises, as was done in the current study, are instructional practices that are completely aligned with these national recommendations.

Role-play is perhaps one of the most active of active-learning strategies, and has been used previously to teach a variety of topics relevant to biology education; however, assessment of these role-play activities has been largely qualitative (Farnworth, 2007; Krajsek & Vilhar, 2010; Ross et al., 2008) (but see Sturges et al., 2009). While such assessments have consistently indicated that students enjoy role-play and believe it is helping them to learn, students’ perceptions of their own learning are not always aligned with actual learning and retention of concepts (Bjork, Dunlosky, & Kornell, 2013). Quantitative assessments of the efficacy of role-play activities are still needed.

Sturges et al. (2009) used a pre-test/post-test/exam format to quantitatively evaluate a protein-synthesis role-play exercise, and found that students achieved
significant learning gains on the day of the activity (pre-test to post-test), but no significant changes were observed from the post-test to the exam, less than one week later. The pre-test/post-test format used in the current study was similar to that of Sturges et al. (2009), as were this study’s findings, that the role-play exercise led to significant learning gains, in both the original and the revised versions of the activity. In combination, these results indicate that role-play is an effective instructional tool, at least in the short term. Although Sturges et al. (2009) did test student understanding a third time, the “retention test” occurred within days of the original intervention; it is not entirely surprising, therefore, that student understanding measured on the third test was similar to that measured by the post-test. The inclusion of a ten-week retention test in this study, to assess student understanding of concepts over time, therefore represents an additional contribution of this study to the role-play literature specifically, and to assessments of active learning in general, for which there is a small, but growing, body of research indicating that active learning may promote knowledge retention over time (Cherney, 2008; Trempy et al., 2002).

The assessment of retention in the first iteration of the activity revealed that, on average, students did remember most, but not all, of the concepts that they learned after participating in the original membrane transport activity; moreover, both the long-term learning gains (pre-test to retention test) and losses (post-test to retention test) were significant. This overall pattern of learning gains, followed by partial losses over time, is paralleled in the findings of Reinfried et al. (2012), who looked at learning gains from a curriculum intervention designed to teach eighth-grade students about the greenhouse
effect, and intuitively this is a pattern one would expect to see. Interestingly, in this study, when the curriculum was revised in an effort to improve student understanding of membrane transport in general, and of co-transport specifically, although the mean retention test score was still lower than the mean post-test score, this decline was no longer significant; however, student scores on the retention test were still significantly higher than on the pre-test. Together, these results indicate that the curriculum revision may have contributed to improved retention of key concepts of membrane transport. In addition, while there were no significant differences between the cohorts using the original and the revised curriculum in pre-test, post-test or retention test scores, the revision may have still resulted in improvements in overall student understanding as revealed by higher mean scores on both the post- and retention tests in the group using the new curriculum.

While these data on student learning and retention are generally informative, they only reflect students’ overall conceptual understanding of membrane transport. When student performance in the pilot study was examined more carefully, looking at each of the five concept questions individually, it became apparent that students were not learning all concepts equally. Students struggled with both questions pertaining to co-transport (questions 4 and 5); moreover, not only were students having difficulty understanding the correct answer for each of these questions, each question also had an alternate, incorrect answer that students favored, the MCIA. The curriculum revision was designed to address the concepts covered in these questions more thoroughly, in order
both to increase the number of students with a correct understanding of co-transport, and to concurrently decrease the number of students with these common misconceptions.

The revised curriculum did result in improved student understanding of co-transport. However, these improvements were not distributed evenly between each of the two key concepts covered in questions 4 and 5. For question 4, there were no significant differences between cohorts—students who participated in the activity before, or after, the curriculum revision—on the pre- and post-tests. In both cohorts, students showed an improved understanding of this question on the post-test, and in both cohorts, the MCIA was overcome (i.e., selected by <25% of students) on the post-test. However, in the original study, the improvements observed on this question from pre- to post-test were largely lost after ten weeks. In contrast, students who participated in the revised activity performed significantly better on the retention test than the students who used the original activity design. In cohort 2, there was not only a larger proportion of students with a correct understanding of this question after ten weeks, there was also a corresponding and significant decrease in the proportion of students who chose the MCIA on the retention test. Thus, while the original activity was sufficient to improve student understanding and to overcome the MCIA in the short-term for question 4, the revised curriculum appears to have led to long-term retention of these improvements.

Trends in student understanding over time were quite different for question 5, both within and between cohorts. Very few students in the original study answered question 5 correctly on any test, and although the proportion of students who correctly answered this question was slightly higher on each of the three tests (pre-, post- and
retention) for the cohort that used the revised curriculum, none of these between-cohort differences was significant, and at best, only half of the students answered this question correctly in either cohort. In addition, the MCIA for question 5 was never overcome. The proportion of students from the second cohort (i.e., the post-revision group) who chose the MCIA was lower on all three tests; however, it appears that these changes were not entirely the result of an increased preference for the correct answer, as one would hope. Rather, they resulted in part from the increased selection of another incorrect answer. Clearly, question 5 is conceptually difficult for students, and these difficulties have persisted despite focused efforts to improve student understanding through a curriculum revision.

Evaluating these very different outcomes for questions 4 and 5 in relation to the original hypothesis, that targeted curriculum revisions would improve student understanding of co-transport, the intervention seems to have been successful for the concepts of question 4, but much less so for question 5. On the positive side, this means that using action research (T. R. Anderson, 2007; Gall, Gall, & Borg, 2003) to identify student difficulties and adjust the curriculum accordingly may result in desired learning outcomes; however, the goals of this intervention were incompletely met. Action research is an iterative and cyclical process. Given the persistence of the conceptual difficulties students face for question 5, the instructor-researcher must consider the next best steps to take. On one hand, generating another cycle of action research, in which the results of current research are used to further adjust the curriculum to address student misunderstandings, might lead to improved learning outcomes. However, two rounds of
curriculum assessment have shown that introductory biology students struggle with the ideas covered in question 5 on multiple levels, even while demonstrating improved understanding of the closely related concepts from question 4.

This discrepancy between questions may result in part from the underlying nature of each of these questions. Question 4 is much more general, and asks students to understand broadly how co-transport works (i.e., it is active, but it does not directly use ATP). Question 5 digs deeper and asks students to understand the specific mechanism that governs this type of transport; they need to understand that electrochemical gradients drive this type of transport, but they also need to understand how electrochemical gradients drive this type of transport, including an understanding of the directional movement of the ions and molecules involved. Conceptually, this is a more difficult question, which may explain why it is causing students to struggle.

Another factor that may be contributing to limited student understanding of this fifth and final question from the survey is cognitive overload (Wieman, 2007; Wieman & Perkins, 2005). Our short-term memories are limited in the amount of new information that they can take in and assimilate in a given period of time; at some point, if too much information is presented at once, it will not all be incorporated or retained. Moreover, new information is more readily processed when it is integrated with pre-existing knowledge (Wieman, 2007; Wieman & Perkins, 2005). Therefore, students may be having trouble with the concepts of question 5 both because they are presented at the end of the activity, after a large amount of potentially new information has already been
learned, and because the concepts of question 5 build on the concepts of question 4 which are themselves newly acquired information for many students.

Given the continued difficulty that students are having understanding the concepts covered in question 5, the instructor must ultimately decide whether to keep including this material in the curriculum. Dirks, Wenderoth, and Withers (2014) suggest that an instructor should ask three key questions when making these types of curricular decisions. First, are students likely to retain the material that is being covered? Second, is an understanding of the concepts in question necessary for the students to construct additional knowledge? And finally, what are the consequences if students do not retain an understanding of the material? Students will gain additional exposure to the concepts of co-transport as they progress through their undergraduate biology coursework, and it may be that for many students, a deeper understanding of these concepts will require the stronger foundation in biology that is the natural result of this progression.

The different trajectories of student learning observed for questions 4 and 5, in response to the same curriculum revision, are illustrative of a more general truth in education: learning is complex. This point is further illustrated by the wide range of learning and retention patterns that were revealed in the pilot study. While the majority of students did learn from the activity—the four most common patterns all exhibited initial improvements—when retention was added to the picture students were quite variable—after ten weeks, there were students who showed continued improvement, and students whose scores were lower than on the original pre-test. This variability is reflected in the large standard deviations around each mean, and highlights another important and fundamental
reality of teaching: students are very different from one another, on many different levels. College students today are considerably more diverse than in the past, coming from backgrounds that vary in a number of factors including ethnicity, socioeconomic status, and academic preparation (Freeman et al., 2011; PCAST, 2012). These differences need to be considered both in our pedagogical decisions, as we try to design curricula that appeal to this broad student base (W. L. Anderson et al., 2005; Freeman et al., 2011; PCAST, 2012), and also in our approaches to evaluating our teaching, as initial student differences can affect perceived learning outcomes (Theobald & Freeman, 2014).

The variety and proportions of these different patterns were quite similar between cohorts 1 and 2, indicating that certain temporal patterns are more likely to occur, with by far the most common pattern reflecting the overall pattern of student mean scores: students learn, and they remember some, but not all, of these new ideas (i.e., LHM). However, these patterns may depend less on academic and demographic variables, as was originally posited, and may in fact be an artifact of the actual level of a student’s score on each test. The observation that the initial level of a students’ performance will have an effect on any conclusions that can be made regarding learning gains (or losses) is a consideration that has been a part of science education research for years, perhaps most famously espoused in Hake’s (1998) review of active vs. passive learning in physics courses. His methods incorporated the measurement of normalized learning gains—gains calculated as a proportion of possible gains—rather than absolute learning gains—the raw difference in scores. Students with higher initial scores have less absolute room for improvement. Thus, even if these students have a perfect score on the post-test, their
absolute learning gains may be less than some students with very low initial scores and moderately low final scores. Any observations about changes in student understanding over time must therefore ultimately take into account the effects that initial student differences and methods of calculation may have on the conclusions that are made (Theobald & Freeman, 2014).

When academic and demographic variables were compared to student test scores, there were few significant relationships. In fact, the only demographic factor that affected any test score was the highly significant effect of ethnicity on post-test score. Asian students did not perform as well on the post-test as Caucasian or URM students. While it is difficult to determine exactly why this was so, it is possible that something about the highly active nature of this exercise, which is one of its defining characteristics, is less conducive to learning for this student population. For example, a number of ESL/EFL (English as a Second/Foreign Language) instructors have made the observation that Asian students tend to be reserved or reticent (Cheng, 2000), characteristics that are not entirely compatible with the on-the-spot, interactive nature of this exercise. Although these accounts are largely anecdotal, and although Cheng (2000) points out that such observations may be less a result of cultural differences than a result of certain types of teaching methodologies or of insufficient language skills, this activity may represent a methodology that is less appealing to these students. Alternately, it may be that language proficiency, which could certainly affect immediate learning in the fast-paced, spontaneous environment of this activity, covaries with ethnicity in this study population.
In another study, Zane et al. (1991) found that Asian-American college students were less assertive than Caucasian students in encounters with strangers, and that Asian-American students experienced higher levels of anxiety in encounters requiring assertiveness, even when their response was equivalent to that of Caucasian students. Since this activity was conducted early in the semester (week 4), it is very likely that many classmates would perceive one another as strangers; considering that the highly interactive nature of this activity does require some degree of assertiveness from participants, this factor may have resulted in lower levels of interaction and participation in the activities by Asian-American students. This circumstance, coupled with potentially elevated anxiety, could certainly affect learning outcomes, as anxiety could reduce processing efficiency and attentional focus (Derakshan & Eysenck, 2009).

The absence of any other demographic effects on student learning from this activity is actually a positive outcome in that it indicates that this activity truly is something that can appeal to a wide range of students, and from which many different types of students can learn. Even the observed effect of ethnicity on post-test score has positive facets. Although Asian students did not learn as much from the activity directly, as measured on the post-test, their learning and retention of these concepts over time were not affected, as evidenced by retention test scores that were not statistically different from those of their peers. In addition, URM students, a group that is generally considered to be at-risk for dropping or failing out of the sciences for a variety of reasons (Freeman et al., 2007), performed as well as Caucasian students, meaning that this activity is providing an effective learning environment for a group of students who may otherwise
have difficulty learning in a traditionally structured academic environment and culture (W. L. Anderson et al., 2005; Ibarra, 2001).

The only relationships between student scores on the pre-, post- and retention tests, and the academic variables GPA and lecture exam score, were two small, but significant, correlations between lecture exam score, and the post- and retention test scores. The fact that students who do well on tests of learning for a specific concept within a course may also be those students who perform well in the course overall is not entirely surprising. Theobald and Freeman (2014) have found that such variables as GPA and grade in a previous biology course can be used to predict student performance in the classroom, and point out that it is therefore important to consider the effects of student characteristics on learning gains. Students who did well on the post-test may have been those with a better understanding of biology in general, or those who grasp these types of concepts more quickly; both are characteristics that could also lead to improved performance in the lecture portion of the course. Students who did well on the retention test, in week 14 of the course, may have been those who achieved a deeper understanding of membrane transport and who were able to integrate this knowledge with other concepts covered in the course; again, characteristics that would also lead to higher scores on the lecture exams. However, the fact that these correlations were quite small indicates that there are many other factors that are contributing to student learning and retention over time.
CONCLUSION

The *Lights, Camera, Acting Transport!* activity is an active-learning exercise that was introduced into the Bio 2 curriculum in response to a large body of science-education research indicating that active-learning contributes to improved student learning in the sciences. Quantitative assessment of student understanding, using a pre-test/post-test/post-retention test instrument, revealed that students learn from this role-play activity, and that initial learning gains are largely retained after ten weeks. However, a closer examination of these results revealed that students were not learning all concepts equally well, and that individual students showed many different patterns of learning and retention over time. This preliminary assessment and evaluation were used as a starting point for the current action research study, in which a critical review of the activity was used to revise the curriculum in an effort to overcome identified student difficulties and improve student learning outcomes, and in which the demographic and academic characteristics of students were considered in relation to learning outcomes to determine whether such attributes are related to student learning from this exercise.

Although the revised curriculum did not lead to any significant improvement in student scores on the pre-, post- or retention tests, students who participated in the new activity attained higher mean scores on both the post- and retention tests. In addition, the decline in mean score from the post-test to the retention test, observed in both groups, was no longer significant for those students using the revised version of the activity protocol. Thus, although the differences in test scores, between students in the original
pilot study and students using the new curriculum, were not significant, students did benefit overall from the revision.

Modifying the curriculum to specifically address the conceptual difficulties that many students were experiencing regarding co-transport did result in significantly improved understanding of the concepts covered in question 4; however, only minimal improvements were observed for the concepts of question 5. Taken together, these results highlight both the successes that are possible, and the limitations that may exist, when undertaking a thoughtful and research-based curriculum intervention. However, the retention of learning gains for question 4, combined with the successful and lasting reduction in the MCIA for that question, demonstrate that the curriculum revision may have had a long-term benefit for student understanding of co-transport.

Evaluating the possible influence of demographic and academic characteristics on student scores on the pre-, post- and retention tests revealed that overall, student performance was not affected by these variables. However, there was a significant influence of ethnicity on student performance on the post-test, which measured student learning immediately after the activity. Asian students did not perform as well on this test as either Caucasian or URM students. It may be that the extremely interactive and unrehearsed nature of this activity creates a learning environment that is less favorable for some Asian students, at least in the short term. However, there is also a positive result revealed by these ethnicity data—the URM students in this study performed as well as their Caucasian classmates, and better than the Asian students. This is a group of students that often underperforms in traditional classroom settings, and there have been national
calls to generate curricula that will help such students enter into, and succeed in, the sciences; this activity therefore represents a pedagogical tool that could be used in the classroom to further these goals.

There was also a slight correlation between student performance in the lecture portion of the course, and students’ scores on both the post-test and the retention test. This correlation is not surprising, as students who readily understand one aspect of biology may also understand biology in general more easily. However, the fact that these correlations were quite small also speaks to the existence of considerable variability in student learning, and suggests that this is an activity from which students at many different academic levels can learn. Similarly, the absence of any other significant relationships, besides that observed for ethnicity, between student scores on the pre-, post- and retention tests and any other demographic variable indicates that this activity does have the potential to benefit a very diverse student body.

This study illustrates the effective application of action research to evaluate, revise, and ultimately improve a curriculum exercise. In addition, it shows that there are persistent areas of difficulty in students’ understandings of co-transport, and it reveals that this exercise did not benefit students of all ethnicities equally, at least in the short term. These results can be used to make curriculum decisions regarding the level of detailed instruction on co-transport that would be most beneficial for students within this exercise, and to consider ways in which the current exercise could be modified to create a learning environment that is more favorable to all students.
By incorporating unique and active exercises into our science teaching, followed by the critical examination of student learning outcomes from these activities, science instructors can build curricula that are more effective, and that are aligned with national goals advocating the increased use of instructional strategies that have been shown, through empirical scientific research, to work. As scientific educators work together to respond to these objectives, we will work towards the ultimate goals of recruiting and retaining more students in the sciences, and generating a large, diverse and thriving community of scientists as our nation moves forward in the 21st century.
APPENDIX A

Pre-activity worksheet

1. Fill out the following chart comparing different mechanisms of transport across a plasma membrane:

<table>
<thead>
<tr>
<th>Types of molecules transported? (List size, polarity, charge)</th>
<th>Simple Diffusion</th>
<th>Facilitated Diffusion</th>
<th>Active Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requires a carrier or channel protein? (Yes/No)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Requires an additional energy source? (Yes/No)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do any molecules travel against their concentration gradients? (Yes/No)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. What is meant by the term “membrane potential”? What is an electrochemical gradient?

3. What type of membrane protein does the cell use to generate a membrane potential?

4. Briefly describe the 6 steps involved in ion transport using the Na⁺/K⁺ pump.

5. What specifically would happen to a cell if its Na⁺/K⁺ pump were defective? (Hint: “It would die” is not an acceptable answer.)

6. What is a cotransporter?

7. Why are electrochemical gradients important to the process of co-transport?

8. Is the Na⁺/K⁺ pump considered a cotransporter (Yes/No)? Why or why not?
APPENDIX B

Activity instructions

Summary
In this activity, students act out the basic mechanisms of passive and active transport of substances across the plasma membrane. Students assuming the role of phospholipids and membrane proteins decide the fate of other students who are representing a range of substances, including those that can proceed across the membrane via simple diffusion and those requiring a specialize channel, carrier or pump. The play is divided into three acts: Act I explores simple and facilitated diffusion, Act II features a Na⁺/K⁺ electrogenic pump (primary active transport), and Act III introduces co-transport (secondary active transport).

Learning Objectives
At the end of this activity, students should be able to:

- Compare and contrast the mechanisms of simple diffusion, facilitated diffusion, and active transport (both primary and secondary).
- Identify, and provide a rationale for, the mechanism(s) by which various substances cross the plasma membrane.
● Describe the steps involved in the transport of ions by the Na\(^+/\)K\(^+\) pump and explain the importance of electrogenic pumps to the generation and maintenance of membrane potentials.

● Explain the function of electrochemical gradients as potential energy sources specifically used in secondary active transport.

● Relate each molecule involved in co-transport to its own concentration gradient, and describe which molecules travel with and against these gradients.

**Materials**

● A room that allows for the creation of a plasma membrane (tables, chairs or desks can be used), and that has space for students to move around.

● A chalkboard or whiteboard to use for stage directions, Think-Pair-Share prompts, and explanations.

● Role cards labeled with the names of the molecules and ions that students will be impersonating. These can be created by writing the terms on construction paper, cardboard, or large note cards. Multiple cards will be needed for some terms, so color-coded cards are recommended (e.g., all H\(_2\)O molecules are on blue paper).

● Index cards for students to use when brainstorming about their subcellular identities.
Documents for Students

There are no documents for students in class. However, students can bring notes and/or their texts to class.

Estimated Time Frame for Activity

This activity can be performed during a single 110-minute lesson, although the activity can be streamlined to a 45-minute or 1-hour session, especially if preparation and review are done in advance.

Student Background and Preparation

Students should come to class prepared, having read the section of their text pertaining to membrane structure and function, and having completed the Pre-Activity Worksheet.

Tips for Success

- Give students background information before each act begins, and use the board liberally to give directions, explanations, and stage instructions, as outlined in each act.
- It is helpful to draw very basic stage directions on the board at the start of each act, so students are familiar with the fundamental layout (e.g. where the membrane is located and what constitutes the interior and exterior of the cell). Additional details can be added or withheld according to the rest of the protocol for that act.
• Provide plenty of guidance through the first act, while students get comfortable with the activity.

• An intermediate level of structure is ideal for all acts, one in which students follow enough of the protocol for the sequences to flow (with only one interaction showcased at a time), but still have enough freedom to ad lib and inquire. It is critical that students slow down and vocalize their decisions every step of the way.

• Circulate the room during the small group sessions, and ask questions to stimulate engagement.

• Involve all students in every act; be sure to ask and invite questions throughout the play. Different students will have varying levels of responsibility in each act, so be sure to call on different students throughout, asking them to validate decisions that are being made.

• As the play continues, students generally become more relaxed and begin asking questions and offering explanations more readily. However, be sure to save time to review concepts and answer any lingering questions at the end of each act.

**Assessment Strategy**

Assessment is ongoing throughout this activity. It is easy to gauge what students know through their actions and responses; questioning their decisions and evaluating their responses can provide additional knowledge. Immediate feedback is provided as the instructor plays the role of the director of the play. In addition, the Pre-Activity Survey and Post-Activity Survey can be administered before and after the activity to assess
student learning gains, and the Retention Survey can be administered after ten weeks to assess retention of concepts. Students can be asked to use anonymous IDs (e.g. last four digits of phone numbers) in lieu of their names, if desired.

**Instructional Strategy**

**General Instructions**

1. If students completed the Pre-Activity Worksheet, you may choose to go over the answers as a class before starting the rest of the activity.

2. Provide students with a general description of the activity and the learning objectives. Explain that they will be the actors in a three-act play that will help them understand the various ways that substances pass into and out of the cell (this being a critical function of the plasma membrane in sustaining homeostasis and life). Describe your role as a director who will make suggestions and prompt students to “consider the motivation” for their actions. In addition, explain that throughout this activity, students will be asked to take notes on index cards, and to participate in Think-Pair-Share exercises (described below).

3. Before each act, introduce students to the stage setup, pointing out what constitutes the plasma membrane, and the interior and exterior of the cell. The board will also be an important tool, for sketching out stage directions and prompts as outlined below.
ACT I: The Selective Barrier

The cast: 4 phospholipids, 1 Na\(^{+}\) ion channel, 1 K\(^{+}\) ion channel, 1 aquaporin, 1 glucose transporter, 1 amino acid transporter; 1 of each of the following: O\(_2\), Na\(^{+}\), K\(^{+}\), hydrocarbon, methionine, glucose, H\(_2\)O, CO\(_2\), ATP (18 total).

1. *Introduce Act I.* “Club Cell” is an exclusive nightclub in Sacramento, and a variety of molecules and ions (the “public”) line up each evening hoping to get in. Four phospholipids (the “bouncers”) staff the main entrance and decide if the substances in the line to enter the cell meet the “dress code” to cross the bilayer and enter the cell. The phospholipids must discuss each candidate and agree on a decision while providing an explanation as to why they let some substances enter, while denying entry to others. All substances must begin at this entry point; those that are turned away can either argue their case (if they feel that they were unjustly denied entrance) or look for another way into Club Cell along the plasma membrane. These alternate entries are manned by channel and carrier proteins that cater to a different clientele (i.e. larger, charged, and hydrophilic substances).

2. *Think.* Randomly distribute role cards and index cards to students for Act I. Separate the membrane components from the public as you pass out the cards. Ask all students to individually think about their identities and write down important points on their index cards. For members of the public, ask them to think about size, polarity, charge, and whether they should be allowed to enter at the main entrance or what they might need to cross the membrane. For membrane components, ask them to think about which substances they will allow to cross.
3. **Pair.** Ask students to form small groups (3-4 individuals) to review and discuss the identity notes of each student in the group. Encourage them to make changes as needed. The public should work with the public, the phospholipids together, and other membrane components with each other.

4. **Share.** Assign the components of the plasma membrane to their positions; a good first exercise for the class as a whole is to ask the phospholipids how they think they should arrange themselves (i.e. as a bilayer) and why. Encourage feedback from all students. Next, line up the public outside of the club, and students are ready to begin with the first substance in line, who should start by introducing him/herself to the bouncers, and asking for admission into Club Cell. Substances that are rejected by the phospholipids must look for another way in by talking to the other membrane components. Remind students to use their notes to vocally justify all decisions and (if necessary) contestations.

5. After all substances are in Club Cell (or have been permanently denied entry), collect the role cards and ask students to return to their seats. Review major concepts on the board, and invite student questions and feedback.

**ACT II: Pump It Up! (the Concentration Gradient)**

The cast: 8 Na\(^+\) ions, 8 K\(^+\) ions, 2 students as the Na\(^+\)/K\(^+\) pump, 1 adenosine, 3 phosphates, 1 Na\(^+\) channel, 1 K\(^+\) channel (24 total).
1. **Introduce Act II.** The purpose of this act is to introduce the concept of a membrane potential (form and function), and to illustrate how a cell establishes and maintains its membrane potential.

2. **Think.** Pass out a new set of index cards. On the board, to the side, write up a “preliminary cast” of 8 Na\(^+\) ions and 8 K\(^+\) ions. In the center of the board, sketch a simple membrane (no proteins), and label the inside and outside of the cell. Point out to students that the membrane currently has no transport proteins, and ask students how they would distribute the current cast of ions to mimic the membrane potential of a real cell. Specific questions to consider: 1) What is a membrane potential and what is its purpose? 2) Is the inside of the cell positive, neutral, or negative in relation to the outside? 3) Is the concentration of Na\(^+\) inside of the cell higher than, equal to, or lower than outside of the cell? 4) Is the concentration of K\(^+\) inside of the cell higher than, equal to, or lower than outside of the cell?

3. **Pair.** Have students work in small groups of 3-4 to answer the questions above. Each group must agree upon a distribution for the cast.

4. **Share.** Pass out the Na\(^+\) and K\(^+\) cards. Using the Socratic method, pick a group to begin, and ask them to arrange the ions on stage according to their plan. Ask the next group if they agree; if not, ask them to rearrange the ions. Ask other groups for feedback until all groups are in agreement or an agreement cannot be reached. At this point, move ions into the following arrangement as needed: 6 Na\(^+\) and 2 K\(^+\) ions outside of the cell; 2 Na\(^+\) and 6 K\(^+\) ions inside the cell. Explain that this arrangement represents the normal membrane potential of the cell, and discuss any points of
confusion. In addition, be sure to discuss the answers to the Think-Pair-Share questions above.

5. Ask students if any movement of ions can occur across this membrane. They may recognize that there is a steep concentration gradient across the membrane for both Na\(^+\) and K\(^+\), but should also recognize that the two ions cannot move across the phospholipid barrier. Therefore, no movement can occur.

6. Think/Pair. Write the rest of the cast up on the board, and pass out the remainder of the role cards. Ask the ions to consider whether they are “inclined” to cross the membrane under current conditions, why or why not, and what would be required for any movement based on the new cast members. Ask the new players to consider who they are, where they should be situated, and how they might interact with the rest of the cast. Students can work independently or discuss with a partner if they wish.

7. Share. Introduce the ion channels to the membrane. Ask the ions to respond to this addition, one volunteer molecule at a time. If volunteers are scarce, start calling on students. Emphasize to the ion channels that no one gets across without verbal justification. Cast members currently in the wings are encouraged to give input until agreement is reached by all. (Na\(^+\) and K\(^+\) should move down their concentration gradients until the ion concentrations are balanced.)

8. Thank the ion channels for their hard work and remove them from the membrane. Explain that the membrane potential is disrupted and must be restored. Ask students how the cell will accomplish this (i.e. with a Na\(^+\)/K\(^+\) pump and ATP to power it).
9. Ask the final cast members (Na\(^+\)/K\(^+\) pump and ATP) to find their places on stage.

Have the Na\(^+\)/K\(^+\) pump go through one round of pumping ions (go through each step described in the Pre-Activity Worksheet, including the cycling of ATP to ADP in which one phosphate group needs to be donated to, and later released from, the pump). This will restore the concentration gradient and negative cell interior.

Encourage the ion channels in the wings to give feedback as warranted.

10. After Act II, collect role cards and have students return to their seats. Review major concepts and invite student questions and feedback.

ACT III: Gatorade: Is it in you?

The cast: 9 glucose molecules, 8 Na\(^+\) ions, 2 students as the Na\(^+\)/glucose cotransporter (19 total).

1. **Introduce Act III.** To continue the analogy of Club Cell, after dancing for hours in the hot dance club, you find yourself depleted of fluids and energy. This is nothing a nice cold Gatorade can’t cure! The purpose of this act is to show how cotransporters function, using the example of the Na\(^+\)/glucose cotransporter (SGLT1) that is essential for the uptake of glucose in the lumen of the intestine.

2. **Think.** Pass out index cards and write the full cast list on the board, to the side. Tell students that this act is about co-transport. The body wants to get glucose into the cell, but there is a problem—glucose would have to move up its concentration gradient, and there is no ATP in sight. Draw the basic membrane (i.e. no proteins in it yet) on the board, label the inside and outside of the cell, and add the following
information for glucose: 145 mM concentration outside, 150 mM concentration inside. For now, let students think about how to distribute the Na\textsuperscript{+} ions. Given this template, ask students to sketch out the opening positions for all cast members, and to respond to the following questions: 1) is co-transport active or passive transport? 2) what force drives the movement of molecules in co-transport?

3. *Pair.* Have students work in small groups of 3-4 to answer the questions above. Each group must agree upon opening positions for the cast.

4. *Share.* Again using the Socratic method, pick a group to begin, and ask them to draw starting stage directions on the board, including the location of all molecules involved. Ask the next group if they agree; if not, ask them to change it, and so on until agreement (or resilient lack of) has been reached. At this point, make any adjustments needed on the board so that there are 4 glucose molecules and 8 Na\textsuperscript{+} ions in line for Club Cell ("outside," in the lumen of the intestine); 5 glucose molecules and no Na\textsuperscript{+} ions inside of Club Cell; and the Na\textsuperscript{+}/glucose cotransporter in the membrane of this intestinal cell. With any changes that are made, ask the class to propose an explanation, and discuss the answers to questions 1 and 2 above. Be sure to point out that there is no ATP in the cast for this act, and ask students to explain why this is so.

5. *Think.* Pass out the role cards. Ask students to think about: 1) what role their own character should play, including how concentration gradients will influence their actions (does this depend on location?); 2) how concentration gradients will affect the
movement of other characters (who gets to move and why?); and 3) how a 
Na\(^+\)/glucose cotransporter might work.

6. **Pair.** Ask the students to find a partner (or two) with the same identity with whom to 
discuss their character and answer the above questions. For this discussion, the 
instructor should be sure to spend some time with the cotransporter pair and, as 
needed, guide their understanding of cotransporter function—this cotransporter will 
only let Na\(^+\) and glucose in together, in a 2:1 ratio (2 Na\(^+\) ions bring in 1 glucose), and 
only while the concentration gradient for Na\(^+\) exists.

7. **Share.** Set up the characters according to the stage directions on the board. In turn, 
ask the students playing Na\(^+\), then glucose, both inside, and outside of the cell, 
whether they will be moving up or down their concentration gradients, and ask all 
students to look at the stage and identify an energy source that can be used to get 
glucose into the cell. This portion can be conducted like a series of interviews on 
Extra or a similar entertainment show. “We’re standing outside of Club Cell, talking 
to some would-be patrons. Who are you? How do like Club Cell? Why do you want 
to get in? How will you go about it?”

8. The students should be ready to begin. Similar to Act I, the way into Club Cell is 
through the main entrance, which is now manned by a cotransporter. As students in 
line approach the cotransporter, they must try to justify their entry into Club Cell, and 
the cotransporter has to justify who gets in and why—what criteria must be met? The 
cotransporter can give students hints (e.g. “You can’t come in by yourself” or “You 
need more Na\(^+\)!”) but should avoid giving away all information at once. Students who
are denied individually will have to go to the back of the line, and will have to find the right partners in order to eventually get in. In addition, the line outside will get shorter only as long as there is a gradient to “pay” the price of admission.

9. Once the action has stopped (i.e. students have figured out how to use the cotransporter, and the Na\(^+\) gradient is gone, after two cycles), reiterate to everyone that it is ions moving with their concentration gradients that power cotransport; only glucose is moving against a gradient. Ask students to explain how the cell would re-establish the concentration gradient to power the continued use of this cotransporter (i.e., Na\(^+\)/K\(^+\) pumps).

10. Collect the role cards and have students return to their seats. Review key concepts and answer any final questions. This is an excellent time to reinforce the idea that all of the activities covered in all three acts are working simultaneously to accommodate the dynamic needs of the cell. For instance, in Act III, there would also be aquaporins in the membrane allowing water to enter the cell along its own concentration gradient (from a hypotonic to a hypertonic environment).
APPENDIX C

Concept questions for the pre-, post- and retention tests

1. Which of the following substances can easily diffuse across the lipid bilayer of the cell membrane? (Circle all that apply.)
   a. H₂O
   b. K⁺
   c. O₂
   d. CO₂
   e. hydrocarbons
   f. glucose
   g. ATP

2. Which of the following statements about facilitated diffusion and active transport is true?
   a. They both require proteins, and are therefore both considered forms of active transport.
   b. Facilitated diffusion involves channel proteins, whereas active transport involves carrier proteins.
   c. They both transport substances against their concentration gradients.
   d. Active transport requires energy, whereas facilitated diffusion is driven by concentration gradient alone.
3. The primary role of the sodium-potassium pump…
   a. *is to create and maintain a membrane potential across animal cell membranes.*
   b. is to balance the charges across the cell membranes of animal cells.
   c. is to build up potassium outside the cell and sodium inside the cell.
   d. is to regenerate ATP by adding a phosphate to ADP.

4. The mechanism of co-transport…
   a. is a type of active transport that requires energy in the form of ATP.
   b. *is a type of active transport that does NOT require energy in the form of ATP.*
   c. is a type of passive transport that does NOT require energy in the form of ATP.
   d. is a type of passive transport that requires energy in the form of ATP.

5. A sodium-glucose co-transporter…
   a. transports **sodium only** against its concentration gradient.
   b. *transports glucose only against its concentration gradient.*
   c. transports both sodium and glucose against their concentration gradients.
   d. transports neither sodium nor glucose against their concentration gradients.
Demographic survey

1. What is your gender?
   a. Male
   b. Female
   c. I prefer not to answer

2. What is your ethnicity?
   a. Asian
   b. Hispanic
   c. Caucasian, non-Hispanic
   d. African-American
   e. Native American / Alaskan Native / Pacific Islander
   f. Other (please specify) _________________________________
   g. I prefer not to answer

3. At the beginning of this semester, what was your GPA? __________
   (If you prefer not to answer, please write “N/A”)

APPENDIX D
4. If you are currently employed, how many hours do you work each week?
   a. 10 hours or less
   b. 11-20 hours
   c. 21-30 hours
   d. More than 30 hours
   e. I prefer not to answer

5. Do you consider yourself to be a nontraditional student?
   a. Yes
   b. No
   c. I prefer not to answer

6. What is the highest level of education completed by either of your parents?
   a. Did not finish high school
   b. High school graduate or GED
   c. Trade school or Associate’s degree
   d. Bachelor’s degree
   e. Master’s degree
   f. Terminal degree (doctorate or similar)
   g. I prefer not to answer
7. At the beginning of this semester, which of the following describes your academic status?
   a. Freshman
   b. Sophomore
   c. Junior
   d. Senior
   e. I prefer not to answer
You are invited to participate in a study entitled “Lights, Camera, Acting Transport! The Effects of a Curriculum Revision on Student Learning Gains and Retention.” By signing below, you agree to participate in this study.

The goal of this study is to determine whether students are learning and retaining key concepts of membrane transport after participating in the “Lights, Camera, Acting Transport!” activity, and to determine whether there may be additional demographic or academic variables that influence student learning and retention of these concepts. Your participation will help to answer these questions, and will make the introductory biology experience better in the future.

This study will use results from the surveys that you have completed in conjunction with the “Lights, Camera, Acting Transport!” activity (pre-test, post-test and retention test). In addition, this study will use data from a brief demographic survey, and will also use information from your exam scores in “Bio 2: Cells, Molecules and Genes.” By signing this form, you are giving your permission to access and use these data for the study.

Participants’ survey responses and course-performance data will be kept confidential. Data will not be accessed or evaluated until final course grades have been submitted for the semester. In addition, participants’ names will be removed from the
surveys and academic data before any data are evaluated and entered, and anonymous tracking numbers will be assigned and used for the duration of the study. The tracking numbers are necessary only to link results among the surveys and course data. All lists tying names and tracking numbers will be destroyed at the conclusion of data analysis, and electronic files containing this information will be deleted.

Participation in the study is voluntary, and will not affect your grade in any component of the Bio 2 course. You may choose not to participate in the study at any time.

If you have any concerns, or wish to review the surveys before you fill out the consent form, please contact Susanne Gnagy, CSUS, *** Hall ***, ***csus.edu.

Date: ______________

Section and Instructor: __________________________________________

I give my permission to the researchers to use my course data as outlined above:

I agree ____ I do not agree ______

Name of participant (please print):

_______________________________________________________________

Signature of participant:

_______________________________________________________________
APPENDIX F

Instructions for administration of surveys

Week 4 – Instructions

- Before administering the surveys, be sure you have a labeled manila envelope for each section in which to place the completed surveys
- Ask students to be sure to put their names on each sheet
- Emphasize the following to students before the survey is administered:
  1. Names are necessary to pair pre- and post-test scores
  2. Names will only be used to link data
  3. Once data have been linked, all names will be removed and an anonymous study ID used from then on
  4. On the day of the survey, the surveys will be placed in an envelope which will be sealed; the envelopes will not be opened until the semester has ended, and student answers will have no effect on course grades
  5. Encourage students to answer openly and honestly; explain that these data will be used to improve the activity and to inform future teaching, and that all information linking them to individual responses will be destroyed once data have been analyzed
- Administer the survey
After all surveys have been completed, collect, place in envelope, and seal

After class, bring envelope(s) to a secure area for storage

Week 4 – Checklist

- Please follow the order of events outlined in this list

☐ Collect homework

☐ Administer pre-test

☐ Collect pre-tests in a labeled envelope

☐ Review homework

☐ Conduct activity (follow written protocol)

☐ After activity, open up floor for final questions

☐ Administer post-test

☐ Collect post-tests, place in labeled envelope

☐ Review correct answers as a class

☐ Deliver envelope with tests to secure storage in Sequoia 339, with this checklist

☐ Do not return homework to students

☐ Do not inform students in advance about the retention test

Week 14 – Instructions

- Ask students to be sure to put their names on each sheet and emphasize the following to students before the survey is administered:

  1. Names are necessary to pair pre- and post-test scores
2. Names will only be used to link data

3. Once data have been linked, all names will be removed and an anonymous study ID used from then on

4. On the day of the survey, the surveys will be placed in an envelope which will be sealed; the envelopes will not be opened until the semester has ended, and student answers will have no effect on course grades

5. Encourage students to answer openly and honestly; explain that these data will be used to improve the activity and to inform future teaching, and that all information linking them to individual responses will be destroyed once data have been analyzed; in addition, if anything on the demographic survey still makes them uncomfortable, they can choose not to answer

6. Describe the consent form and distribute with the surveys

- Administer the survey
- After all surveys have been completed, collect, place in envelope, and seal
- After class, bring envelope(s) to a secure area for storage

Week 14 – Checklist

☐ Administer retention test and demographic survey, and pass out consent form

☐ Collect surveys and consent forms in a labeled envelope, and seal

☐ Deliver envelope with tests and this checklist to secure storage in Sequoia 339
Student evaluation of concept questions

Please think back to the concept questionnaire that you filled out last week after participating in the “Lights, Camera, Acting Transport!” activity, and respond to the following in the space provided. Please be specific. If you need more room, please continue your answers on the back of this sheet.

1. Did the wording of any of the survey questions confuse you in any way? If so, please explain.

2. Were there any questions for which you felt that there was not an appropriate answer provided? If so, please explain.

3. Do you feel that you got any of the questions wrong as a result of the wording? In other words, did you understand the concept, but choose the wrong answer because of the way the question was written? If so, please elaborate; be sure to specify the answer you chose and why you did not choose the correct answer.
LITERATURE CITED


Hogan, K., Bagley, E., Reubens, A., & Henshaw, B. (2012). Restructuring a large, introductory course to help underrepresented minority and first-generation students perform better. Poster presented at the SABER National Meeting 2012, Minneapolis, MN.


